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Sucesión vegetal temprana tras quemados de residuos de corta en un bosque submediterráneo de interés comunitario.

Early plant succession after slash-pile burning in a sub-Meditarraean forest of community interest

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

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Memoria de Tesis Doctoral presentada por Elena Castoldi para optar al grado de Doctor

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A Olmo

a Michelangelo

ai miei genitori, Gianna e Franco

…e a tutti quelli che viaggiano
in direzione ostinata e contraria

Indice

Resumen

Vegetación y flora de la Estación Biológica UCM: interés de conservación

Las estaciones biológicas son laboratorios silvestres donde se preservan hábitat y especies de interés a conservar. En esta tesis, se ha llevado a cabo, en primer lugar, un estudio sobre la vegetación de la Estación Biológica de la Universidad Complutense 'Finca de Ontalba' (EB-UCM) con el objetivo de conocer su riqueza en hábitats e identificar aquellos con interés de conservación. Se identificaron doce comunidades vegetales agrupadas en los siguientes siete grandes tipos de vegetación: 1) comunidades higrófilas y acuáticas; 2) prados; 3) comunidad pionera de suelos alterados; 4) vegetación herbácea nitrófila de lindero de bosque; 5) vegetación herbácea de lindero de bosque; 6) comunidad arbustiva de orla de bosque; y 7) vegetación forestal. La Estación Biológica alberga, dos tipos de hábitat listado en la Directiva 92/43/CEE con interés a conservar. Estos son: a) cursos de agua de llanura o montanos con vegetación de *Ranunculion fluitantis* y *Callitricho-Batrachion* (hábitat 3260); y b) robledales de *Quercus pyrenaica* del NO Ibérico (hábitat código 9230). Por otra parte, se abordó el estudio florístico de la estación con el objeto de conocer su riqueza florística y la flora con interés a conservar. Se aporta un listado de 280 plantas vasculares encontradas en la Estación Biológica UCM lo que representa que un 0.1% de la extensión del valle del Paular encierre casi un cuarto de su diversidad florística. Se encontraron siete especies de interés regional para su conservación.

Respuesta de la vegetación tras quemas controladas de residuos de corta en un bosque mixto sub-Mediterráneo

Las estaciones biológicas constituyen herramientas importantes para desarrolar actividades docentes y de investigación de campo. En primer lugar se investigó el efecto combinado del peso de la semilla y el número de cotiledones en la germinación de *Pinus sylvestris* var. *iberica* tras someter las semillas a temperaturas que simularon el efecto del fuego. La capacidad germinativa (GC) y el tiempo medio de germinación (MGT) fueron estudiados en experimentos que combinaron cuatro temperaturas diferentes (100°, 125°, 150° y 175°C) y dos tiempos de exposición (1 y 5 minutos), junto a controles (sin tratamiento). Cuatro réplicas de 50 semillas cada una fueron utilizadas en cada tratamiento. Se hidrataron diariamente durante 14 días en cámaras de germinación bajo iluminación constante. Se contaron el número de cotiledones en las plántulas. La germinación fue nula a partir de 125ºC, 5 min. Se encontró que GC y MGT estaban negativamente relacionados entre sí e influidos por la temperatura y el tiempo de exposición. Se detectó que la masa de la semilla seguía teniendo un efecto significativo sobre GC pero no sobre MGT tras determinados

tratamientos moderados con temperatura. El número de cotiledones fue positivamente correlacionado con el peso de la semilla pero no se encontró ninguna correlación con la germinación después de los tratamientos con calor. Por tanto, en *Pinus sylvestris* var. *iberica*, la mayor masa de sus semillas en comparación con otras variedades septentrionales mitiga los efectos negativos de la temperatura sobre la germinación.

Se investigó a continuación la sucesión vegetal post-quemado en los primeros tres años con el objetivo de evaluar cómo el fuego afecta a la composición de especies vegetales y hongos. En 40 parcelas de $1m^2$, 20 situadas en quemados de residuos de corta los años 2008 y 2009 y 20 en prados cercanos a las anteriores tomadas como control se estudió la composición de especies, su cobertura, el número de plántulas de pino y variables ambientales. La sucesión vegetal temprana se caracterizó por tres especies: un musgo (*Funaria hygrometrica*) y dos hongos (*Coltricia perennis* y *Psathyrella pennata*). Con el quemado no se detectaron cambios taxonómicos apreciables a nivel de familia, pero sí una mayor presencia de terófitos y plántulas de pino. Se identificaron dos etapas de sucesión vegetal primaria en relación a la riqueza de especies y a la cobertura de *Funaria hygrometrica*. El fuego aumentó significativamente la densidad de las plántulas de pino: Esta densidad se redujo con el tiempo pero la reducción fue más pronunciada en parcelas no quemadas.

También se estudió las características edáficas tras la quema de residuos de corta. Nuestros resultados muestran que se produce un aumento significativo del pH y de los iones solubles del suelo, y una disminución significativa de la materia orgánica. El suelo a lo largo de los tres primeros años después del quemado experimenta una disminución significativa de concentración en iones.

En esta tesis se prosiguió con un estudio que relacionó la emergencia y la supervivencia de las plántulas de pino silvestre en quemados de residuos de corta con ciclos de sequía en un bosque potencial de melojo. Se estudiaron 5 parcelas quemadas (3 en 2008 y 2 en 2009) y 5 parcelas cercanas no sometidas a quemados (controles). Se marcaron todas las plántulas que emergieron en todas las parcelas tras los quemados. Se contaron un total de 721 plántulas y se siguió su desarrollo a lo largo de los dos primeros años. Se contó el número de cotiledones en las plántulas recién emergidas para relacionarlo con su supervivencia. Ciclos de sequía estival y anual resultaron ser la principal causa de mortalidad de las plántulas. La emergencia y la supervivencia fueron mayores en las parcelas quemadas que en los controles. Las plántulas inmediatamente después de emerger resultaron ser más altas en los controles, pero a lo largo del tiempo esta tendencia se invirtió. El número de cotiledones no influye en la altura de las plántulas, pero se relaciona positivamente

con la probabilidad de supervivencia. A su vez la supervivencia de las plántulas resultó dependiente del dbh (diámetro a la altura del pecho) de los pinos circundantes, de la densidad de los pinos y de la hojarasca del melojo. Por todo esto, el manejo tradicional de las quemas de residuos de corta favorece el mantenimiento del pino silvestre en un bosque mixto de pino y melojo.

Por último, se estudió la lluvia de semillas en las parcelas quemadas y controles con el objetivo de relacionarla con la colonización primaria tras quemas de residuos de corta. La comparación entre la riqueza de especies en lluvia de semillas y la de los primeros estadíos de sucesión reveló un banco de semillas latente en suelos quemados por residuos de corta.

Abstract

Vegetation and flora of the UCM Biological Station: its conservation interest

Biological stations are wild laboratories where habitat and species of conservation interest are preserved. In this thesis we firstly investigated the vegetation in the Complutense University of Madrid Biological Station named 'Finca de Ontalba' (UCM-BS), in order to study its habitats richness and identify those with conservation interest. We identified twelve plant communities grouped into seven homogeneous groups: 1) Hygrophilous and aquatic communities; 2) Meadows; 3) Pioneer community of open disturbed soils; 4) Nitrophilous tall-herb vegetation of forest edge; 5) Forest-edge herbaceous community; 6) Forest-edge scrub community and 7) Forest vegetation. Two habitat types are listed in the Habitat Directive 92/43/EEC: a) Water courses of plain to montane levels with the *Ranunculion fluitantis Callitricho-Batrachion* vegetation (habitat code 3260); b) *Quercus pyrenaica* forests of the NW of Iberian Peninsula (habitat code 9230). Moreover, we studied the floristic composition of the area, in order to explore its richness and its conservation interest. In the UCM-BS we found 280 vascular plants: thus a 0.1 % of the Paular Valley extension enclose nearly a quarter of its floristic diversity. We found several species of regional conservation interest.

Plant response after slash-pile controlled burning in a mixed sub-Mediterranean forest

Biological stations are important tools to carry out teaching and field research activities. The combined effect of seed mass and number of cotyledons in *Pinus*

sylvestris var. *iberica* germination was investigated. We previously treated the seeds with heat which simulated the effect of fire. Germination capacity (GC) and mean germination time (MGT) were studied in experiments that combined four different temperatures (100°, 125°, 150° and 175°C) and two exposure times (1 and 5 minutes), together with controls (no treatment). Four replicates of 50 seeds each were used for each treatment. Seeds were hydrated daily for 14 days in germination chambers under constant illumination. Moreover, we counted the number of cotyledons in germinated seedlings. Germination was null for temperatures higher than 125°C and exposure time of 5 min. GC and MGT were negatively correlated and influenced both by temperature and exposure time. Seed mass was found to have a significant effect on GC at some moderate heat treatment but not on MGT. The number of cotyledons was positively correlated to seed mass but not with germination after seed heat treatments. We concluded that in the case of the Iberian Scots pine, higher seed mass may mitigate the negative effects of temperature on seed germination after moderate heat treatment simulating fire.

In the following chapter we investigated the plant succession after burn in the first three years, in order to assess how fire affects plants and fungi composition. In 40 plots of $1m^2$ each (20 located in slash-pile burns in 2008 and 2009 and 20 near the burns taken as a control) we studied species composition, species cover, number of pine seedlings and environmental variables. Early plant succession was characterized by three species: a bryophyte (*Funaria hygrometrica*) and two fungi (*Coltricia perennis* and *Psathyrella pennata*). No taxonomical changes were detected in vascular plant families but there was an increased presence of therophytes and pine seedlings. Two early vegetation stages were identified relating to species richness and *Funaria hygrometrica* cover. Fire significantly increased pine seedlings density, which subsequently decreased over time. Survival of one-year old pine seedlings was unrelated to the year of the burnt. We highlight the importance of bryophyte and fungi species in comparison to seeder species as indicators of recent prescribed slash-pile burns under a sub-Mediterranean climate. We also point out the impact of prescribed slash-pile burns on pine seedling recruitment after the first years post-fire. This recruitment decelerates over time in burnt sites, and it is more pronounced in control plots.

Edaphic characteristics after slash-pile burns were also studied. Our results show a significant pH and soluble ions increase and a significant reduction of the organic matter. The soil over the first three years after burn undergoes a significant decrease in ionic concentration.

This thesis continued with a study that linked the seedlings emergence and survival of *Pinus sylvestris* after slash-pile burns with drought in a *Quercus pyrenaica* potential forest. We studied 5 burned plots (3 in 2008 and 2 in 2009) and 5 control plots close to the burns. All the seedlings emerged in the plots (721 in total) were individually marked and monitored during two years. The number of cotyledons was counted to relate it to seedling survival. Annual and summer drought were the main cause of seedling mortality. Seedling emergence and survival were higher in burned plots than in controls. Immediately after emergence there was a higher number of seedlings in control plots, but this trend reversed over time. Cotyledon number did not influence seedling height but was positively correlated with survival probability. Seedling survival depended on the dbh (diameter at breast height) of surrounding pine trees, pine tree density and oak litter cover. We concluded that the traditional management system of slash-pile prescribed burns favours the maintenance of Scots pine, especially in a mixed pine-oak forested area.

Finally, seed rain was explored in burnt and control plots in order to relate it to primary colonization after slash-pile burns. The comparison between species richness in seed rain and in the early succession stages revealed a dormant seed bank in slash-pile burns soils.

Introducción

Introducción

Esta tesis doctoral focaliza su estudio en la Estación Biológica UCM y se divide en dos apartados. El se centra en el interés de conservación de la Estación desde un punto de vista eco-botánico. En él se realiza el primer estudio sobre la flora y vegetación de la Estación Biológica UCM. En el segundo apartado nuestro interés se enfocó en el estudio de la sucesión temprana de la vegetación y la respuesta de la germinación del pino silvestre tras la quema de corta de corta. Este manejo consiste en el apilamiento de ramas y restos vegetales en rodales y su posterior quema controlada con el objeto del control y saneamiento del bosque.

Área de estudio

La Estación Biológica UCM Finca de Ontalba se encuentra situada en el Valle del Paular, en las estribaciones meridionales de la Sierra de Guadarrama, dentro de la zona periférica de protección del Parque Nacional de la Sierra de Guadarrama. El valle del Paular es uno de los valles más ricos y mejor conservados de la sierra madrileña (Fernández-González 1991). La sierra Guadarrama está constituida por bloques tectónicos paleozoicos originados durante la orogenia Hercínica (350-250 Ma) que fueron posteriormente afectados por la orogenia Alpina (40-10 Ma) en el Terciario (Mayo 2002). Gneis y granitos constituyen la litología dominante (Guerra et al., 1966). En el valle del Paular se conserva una serie sedimentaria cretácico-terciaria parcialmente desmantelada y fragmentada por la red fluvial y en buena parte soterrada bajo los depósitos aluviales cuaternarios, fluviales y fluvioglaciares. Dentro de la Estación Biológica existen depresiones circulares del terreno (dolinas) a veces rellenas por una lámina de agua (Fig. 1).

En el área de estudio la precipitación media annual es de 895 mm y la temperatura media anual es de 10.1ºC (Elías Castillo y Ruiz Beltrán, 1977, Fig. 2). Los meses de verano son secos y cálidos, mientras que los de invierno son lluviosos y fríos.

Figura 1: Dolina rellena por una lámina de agua en la Estación Biológica UCM.

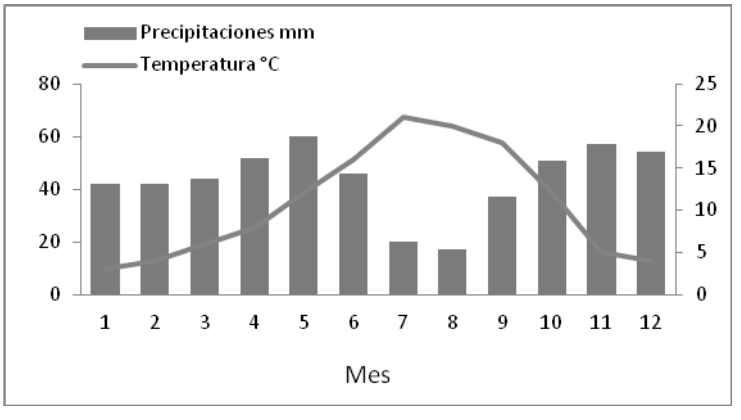

Figura 2: Curva de temperatura media mensual e histograma de precipitaciones medias mensuales de la estación meteorológica situada en Rascafría (Valle del Paular, periodo de observación 2005-2012).

La Estación Biológica está constituida principalmente por un bosque mixto de pino silvestre (*Pinus sylvestris* L.) y roble melojo (*Quercus pyrenaica* Willd.), los dos parcialmente dominates en determinadas áreas (Castoldi 2009, Fig. 3). Estas formaciones boscosas alternan con pastos, orlas de arbustos espinosos, vegetación de ribera y fontinal.

Figura 3: Aspecto de los ambientes forestales presentes en Ontalba. A: dominancia de *Pinus sylvestris* ; B: dominancia de *Quercus pyrenaica*.

La zona donde se enmarca nuestro estudio ha sido objeto de aprovechamiento forestal del pino silvestre y de pastoreo de ganado (Cañellas et al. 2000). Estos manejos se han abandonado en los últimos decenios dentro de la finca lo que ha contribuido al cambio progresivo de pastos y su consecuente emboscamiento. En la actualidad un manejo habitual en el área de estudio, pero también en el conjunto de la Sierra es el de la quema de restos de residuos de corta para el control y el saneamiento del bosque. Las quemas controladas de madera de árboles y arbustos amontonados se realizan normalmente cada año previa solicitud al Registro General

del Ayuntamiento correspondiente. Las quemas se concentran en unos pocos días, frecuentemente antes de finales de mayo para evitar posibles episodios de incendios.

Flora y vegetación de la Estación Biológica 'Finca de Ontalba': interés de conservación

Desde el año 2007 una finca privada de 50 hectáreas con nombre 'Finca de Ontalba' ubicada en la Sierra de Guadarrama (Rascafría) ha pasado a ofrecer su uso como Estación Biológica de la Universidad Complutense de Madrid (Telleria 2007). Un buen número de Universidades de todo el planeta disponen de estaciones biológicas asociadas (Universidad de Sevilla, University of Michigan, University of Oklahoma, Université de Liège). Las Estaciones Biológicas son el escenario adecuado para realizar estudios científicos a corto y largo plazo y para desarrollar actividades formativas y docentes así como son un lugar para la conservación de la biodiversidad (Eisner, 1982; Palacios-Vargas et al. 2007). Los objetivos de este apartado son: a) conocer la flora y vegetación de la Estación Biológica; y b) valorar su interés en conservación basándonos en su contenido en hábitats a conservar y en flora amenazada.

Sucesión vegetal temprana y germinación del pino silvestre tras la quema controlada de residuos de corta en un bosque sub-mediterráneo

Una práctica tradicional común en el área de estudio y en toda la Sierra de Guadarrama y el Sistema Central, es la quema de residuos de corta, que consiste en una limpieza sistemática con tala del sotobosque y de las ramas afectadas por enfermedades. Estos restos van siendo amontonados en pilas que son finalmente quemados periodicamente en pequeños fuegos controlados por el hombre. En literatura no existe ninguna información sobre la colonización vegetal de los sitios quemados; la presente tesis incluye el primer estudio sobre ese tema. La germinación de pino silvestre como respuesta al fuego ha sido ampliamente

estudiada en experimentos de laboratorio (Escudero et al. 1997, Nuñez y Calvo 2000, Habrouck et al. 1999, Álvarez et al. 2007, Castoldi y Molina en prensa), pero hay carencia de información en experimentos en el campo sobre la variedad iberica.

Los objetivos de este apartado son: a) identificar especies indicadores de los quemados de residuos de corta en un ambiente forestal submediterráneo; b) estudiar la sucesión vegetal temprana en estos quemados; c) conocer la respuesta sobre la germinación del pino silvestre de este manejo; d) investigar el efecto combinado de la masa del piñón y del número de cotiledones con la temperatura en la germinación del pino silvestre; e) reconocer factores responsables del mantenimiento del pino silvestre en un bosque potencial de roble melojo.

Material y Métodos

Métodos generales

Sección 1

Capítulo 1

La vegetación fue muestreada de acuerdo con el método fitosociológico (Braun-Blanquet 1979) durante la primavera y el verano de 2009 y 2010. Se estudiaron parcelas en áreas fisionómica y ecológicamente homogéneas (Ellenberg y Dombois 1974). En cada parcela se llevó a cabo un inventario florístico y se recogió la cobertura de cada especie. Los inventarios se reunieron en base a sus similitudes florísticas en tablas que se utilizaron para identificar los tipos de vegetación de acuerdo con Rivas-Martínez et al. (2001). Para identificar los hábitats de interés a conservar nos basamos en la Directiva Hábitat 92/43/CEE y en Bartolomé et al. 2005.

Capítulo 2 y Apéndice 1

El muestreo de la flora se llevó a cabo entre marzo de 2009 y septiembre de 2013 siendo más intenso en los meses de primavera y verano. Se realizaron numerosas rutas aleatorias dentro de la Estación. De la mayor parte de las plantas se recogieron ejemplares con los que se confeccionaron pliegos testigos que se conservan en el Herbario MAF (Facultad de Farmacia, UCM). De las especies raras o amenazadas sólo se tomaron fotografías. La nomenclatura de los taxones está de acuerdo con Castroviejo et al. (1986-2012) o con Tutin et al. (1964-1980). Se identificaron las especies amenazadas de acuerdo con la legislación autonómica de Madrid (Decreto 18/1992).

Sección 2

Capítulo 3

Se seleccionaron 10 pinos silvestres (*Pinus sylvestris* var. *iberica*) sanos de tamaño similar (22 metros de altura media y 48 cm de dbh medio) ubicados en la Estación Biológica de la Universidad Complutense, de los que se recogieron al menos 10 piñas en cada uno, en noviembre de 2011. Se recolectaron un total de 158 piñas antes de su apertura y 23 días antes del experimento. Las piñas se colocaron en una estufa de aire seco a 45 °C durante 24 horas para su apertura. Se recogieron las semillas y se pesaron individualmente. Se asignó cada semilla a una de las dos clases de masa definidas de acuerdo a la distribución bimodal que mostraron los datos. Se estudió la germnación de las semillas combinando cuatro temperaturas diferentes (100°, 125°, 150° y 175°C) y dos tiempos de exposición (1 y 5 minutos) junto con un control (sin tratamiento, Fig. 4). Se usaron cuatro réplicas de 50 semillas cada una en cada tratamiento. Las semillas se colocaron en papel de filtro humedecido con agua purificada. La germinación se realizó a una temperatura constante de 20°C y 28% HR (aire) y 22ºC y 56 % HR (mesas de germinación) bajo iluminación continua de 20 E m-2s-1 (lámpara fluorescente F 40 W/33 RS Cool White luz). Se comprobó la germinación todos los días a la misma hora durante 14 días de acuerdo con el criterio de Come (1970). Las semillas germinadas se dejaron crecer con el fin de estudiar la relación entre el tamaño de la semilla (longitud y anchura) y el número de cotiledones. A continuación se estudió la viabilidad de las semillas germinadas mediante cutting test. Se estimó cada 4 días el porcentaje de cobertura de los hongos en las placas Petri de acuerdo a siete clases previamente establecidas (I:0%, II:2%, III:3-10%, IV:11-25%, V:26-50%, VI:51-75%, VII:76-100%). Los hongos se determinaron taxonómicamente hasta el nivel de género (Seifert et al., 2011). Se calcularon la capacidad germinativa (GC) y el tiempo medio de germinación (MGT) para cada tratamiento de la siguiente manera: GC (%) = (n º germinó semillas / no total. de semillas sembradas) * 100 y MGT (días) = Σ (ti * ni) / Σ ni. Donde ti es el número de días a partir de la fecha de siembra y ni es el número de semillas germinadas cada día (Bewley y Black, 1994). Se verificó la normalidad de los datos

o se transformaron en caso necesario. Se aplicó la prueba t-Student para identificar diferencias en la GC y MGT entre el control y las semillas tratadas. Se utilizó ANOVA de un factor para determinar diferencias significativas entre los tratamientos de calor y la masa de semilla sobre la germinación. Se llevó a cabo una ANOVA de tres factores para analizar juntas las temperaturas (H), los tiempos de exposición (T) y la masa de semillas (S). Se realizó un modelo de regresión generalizada (GRM) para investigar las interacciones entre la masa de la semilla y la temperatura con el tiempo de exposición. Se utilizó el coeficiente de correlación de Spearman y el Análisis de Regresión Linear para relacionar el número de cotiledones y la masa de semilla. Se aplicó la prueba t-Student para comparar el número de cotiledones en tratamientos y en control. Los análisis estadísticos se realizaron utilizando SPSS 13.0 y el software STATISTICA.

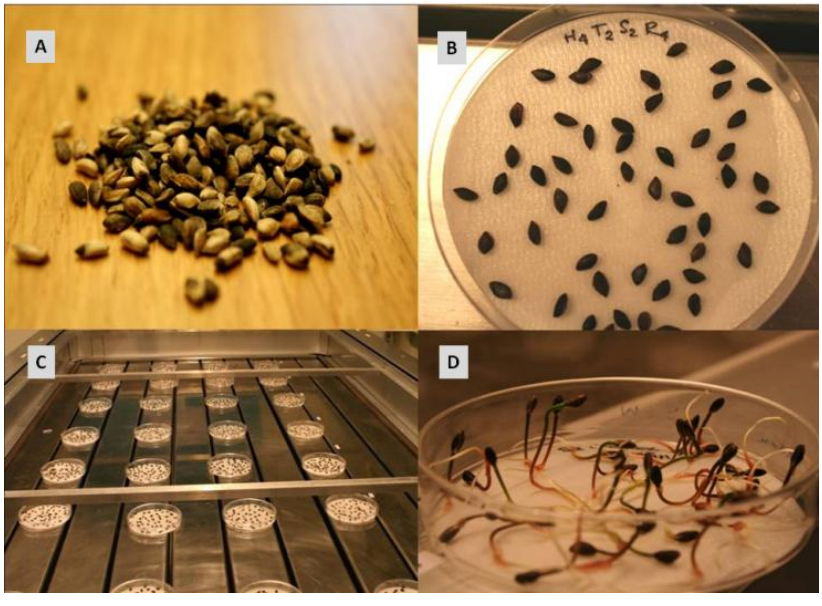

Figura 4: Diferentes fases del estudio experimental del efecto de la temperatura sobre la germinación del pino silvestre después de tratamientos térmicos. A: semillas extraidas de las piñas; B: semillas después de ser tratadas con uno de los tratamientos térmicos en la cápsula petri; C: cápsulas petri en una de las cámaras de germinación repartidas en filas (tratamientos) y columnas (repeticiones); D: semillas germinadas de uno de los tratamientos.

Capítulo 4

Se muestrearon 40 parcelas de $1m^2$ en 2010 y 2011. Veinte parcelas se ubicaron sobre quemados de residuos de corta −10 fueron quemados en 2008 y 10 en 2009− y las veinte parcelas restantes se situaron en las cercanías a los quemados sobre vegetación herbácea no influida por el fuego. En cada parcela se analizó la composición vegetal, la cobertura de las especies vegetales, de la hojarasca de melojo, así como la cobertura de carbón (en parcelas de quemadas, Fig. 5) y el número de piñas. Se estudiaron también determinadas variables relacionadas con la estructura del bosque tales como: cobertura del dosel arbóreo, dbh del pino más cercano y número de pinos en un radio de 15 m circundante las parcelas. En 2010 se contaron las plántulas de pino en los quemados con el fin conocer su supervivencia en los primeros años. Se llevó a cabo un análisis de especies indicadoras (Dufrêne y Legendre, 1997) para identificar las especies primocolonizadoras tras quemados (software PC-ORD 4, McCune y Mefford 1999). Se relaizón una análisis numérico de clasificación mediante Neighbour Joining Tree para examinar la sucesión florística post-fuego (software Syntax 2000). Se utilizó el test de Wilcoxon y el coeficiente de correlación de Spearman para estimar los efectos del fuego en la supervivencia de las plántulas de pino y sus cambios durante los tres primeros años tras el fuego (SAS 9.2, SAS Institute Inc. 2008). Por último, se investigaron las afinidades ambientales entre las parcelas quemadas mediante un análisis de componentes principales (software CANOCO, ter Braak y Šmilauer 2002).

Apéndice 2

Se tomaron muestras del horizonte superficial de suelo (0-10 cm) en 40 parcelas ubicadas en la Estación Biológica UCM, de acuerdo con la metodología ISRIC (Reeuwijk 2002, Fig. 5). De ellas, 30 correspondieron a quemas de residuos de corta −10 parcelas quemadas en 2008, 10 en 2009 y 10 en 2011− y 10 correspondieron a parcelas control no sometidas a ninguna perturbación. Además se recolectó un

cilindro de suelo de volumen conocido con el fin de estimar el porcentaje de humedad gravimétrica. En cuatro parcelas quemadas del 2011 fue posible recoger la capa de cenizas con el objeto de estudiar la composición inicial de los iones. Se analizó la composición iónica de los sales solubles después de una extracción del suelo en agua destilada (1:5) (Fig. 5).

Figura 5: Diferentes fases del estudio de campo y del trabajo de laboratorio para el análisis de suelos. A: muestreo de una parcela permanente quemada; B, C y D: muestreo de las plántulas de pino marcadas y de su altura en una parcela quemada; E: muestreo del horizonte superficial de suelo de una parcela quemada; F y G: fases del análisis de suelo quemado y control en laboratorio; H: muestras de suelo quemado y control en cápsulas para el cálculo de la humedad.

El contenido de aniones (Cl^- NH_4^+, SO_4^{2-}, NO_2^-, NO_3^- y PO_4^{3-}) y cationes (K^+, Na+, Ca^{2+} y Mg^{2+}) fué analizado mediante cromatografía iónica usando un modelo Metrohm 761 Compact IC (Metrohm, Herisau, Suiza) y un fotómetro de llama Sherwood 410 (Sherwood Scientific Ltd., Cambridge, Inglaterra). Se calculó el N inorgánico total a partir de la composición en NH_4^+, NO_2^- y NO_3^- (Knicker et al. 1996). El Carbono orgánico se midió utilizando el método de combustión húmeda, de Walkley-Black. Se determinó la conductividad eléctrica, el pH y la humedad de acuerdo con ISRIC (Reeuwijk 2002). Se siguió el criterio de Munsell (1975) para establecer el color de los suelos. Una ANOVA de dos factores fue realizada con el objeto de comparar las características del suelo entre parcelas quemadas y control y entre parcelas quemadas de diferentes años, teniendo en cuenta las parcelas como grupos independientes (software Statistica).

Capítulo 5

Se estudió la regeneración post quemado de las plántulas de pino silvestre en diez parcelas permanentes de 1 m^2 (Fig. 5). Cinco de estas parcelas correspondieron a quemados de residuos de corta realizadas en 2008 (3 parcelas) y 2009 (2 parcelas) y otras cinco parcelas ubicadas en las cercanías a los quemados pero no sometidas al fuego que actuaron como controles. Los datos de supervivencia de las plántulas se refieren a las 10 parcelas en las que se marcaron individualmente cada plántula. El número de plántulas emergidas se refieren a 40 parcelas −20 quemadas y 20 controles−, incluidas las anteriores. 721 plántulas fueron contadas, marcadas, y medidas en 9 diferentes ocasiones, distribuidas desde abril del 2011 hasta septiembre del 2012. En las parcelas controles se marcaron y midieron también las plántulas nacidas antes del 2010. Se contaron los cotiledones en las plántulas recién emergidas para relacionarlos con su supervivencia. En caso de mortalidad de las plántulas, se registró su causa −sequía estival o herbivorismo−. Se utilizaron los datos metereológicos de los años 2011 y 2012 recogidos en la estación ubicada en el área

de estudio con el objeto de relacionar la supervivencia de plántulas con el clima (Centro de Investigación del Parque Nacional de la Sierra de Guadarrama). Además, se estudió el efecto de las variables estructurales del ambiente de las parcelas detalladas en el capítulo 4. Se comparó mediante t-test pareado la diferencia entre el número de plántulas emergidas en las parcelas quemadas y en las parcelas control. Este mismo tipo de prueba se utilizó también para comparar el porcentaje de plántulas que sobrevivieron después del primer año de crecimiento entre parcelas quemadas y control. Se compararon las alturas de las plántulas por medio de ANOVAs, y la tasa de crecimiento con regresiones lineales. Se exploró la influencia de las variables estructurales en la supervivencia de las plántulas a través de una regresión logística binomial. Los análisis se llevaron a cabo en STATISTICA y SPSS 13.0 software.

Apéndice 3

Se colocaron 12 trampas de césped artificial de plástico de 15 cm de lado después de la eliminación de la vegetación (Molau 1996) en parte de las parcelas estudiadas en el Capítulo 4. Se colocaron seis trampas en quemados del 2008 y seis en quemados del 2009. Se colocó cinta adhesiva alrededor de las trampas de semillas con el fin de evitar la depredación de hormigas granívoras. Se recogieron todas las semillas caídas en las trampas en septiembre de 2010, marzo de 2011 y septiembre de 2011 (inmediatamente después del verano y después del invierno). Tras lo cual las trampas fueron reemplazadas por otras nuevas. También se contaron los estróbilos masculinos de *Pinus sylvestris* recogidos en cada trampa. Las semillas se identificaron a nivel de géneros o especie utilizando un microscopio estereoscópico, con la ayuda del Digital Seed Atlas (Cappers et al. 2006) o de nuestro propio material recogido en la Estación. Se relacionó el valor de la riqueza de especies presentes en los quemados (Capítulo 4) con el del resultado de la lluvia de semillas con el fin de investigar si la colonización es impulsada por el banco de semillas del suelo resistente al fuego o por la lluvia de semillas tras el quemado. Se utilizó un

modelo lineal para determinar diferencias entre las semillas recogidas en el verano y el invierno (software STATISTICA). Se utilizó, además, el Coeficiente de correlación de Spearman para relacionar los estróbilos masculinos de alrededor de las parcelas con el número de pinos, con el fin de tener un indicador de la fitness de los pinos.

SECCIÓN 1

Vegetación y flora de la Estación Biológica UCM: interés de conservación

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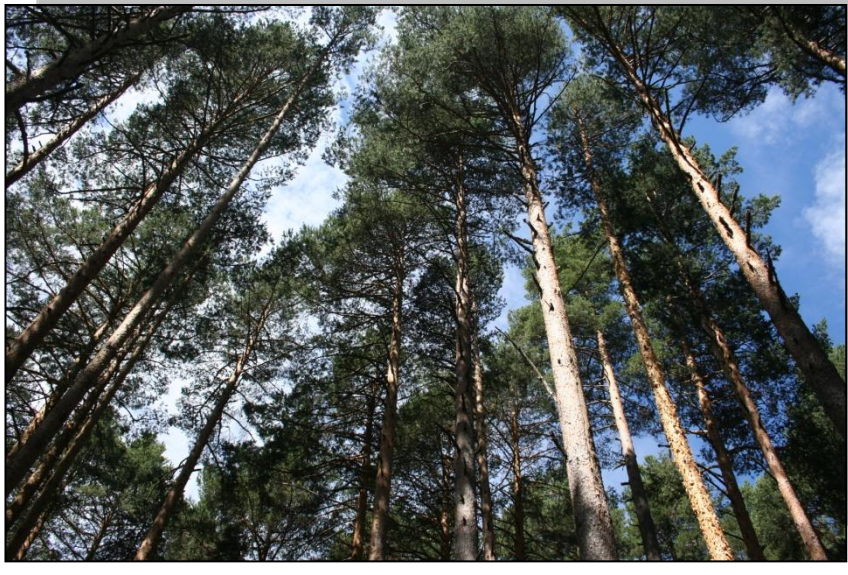
Vegetation and flora of the UCM Biological Station: conservation interest

I.

Vegetación de la Estación Biológica UCM ‘Finca de Ontalba’



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Composición vegetal de la Estación Biológica de la UCM 'Finca de Ontalba'

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RESUMEN

Se ha llevado a cabo un estudio sobre la vegetación de la recientemente designada Estación Biológica Complutense 'Finca de Ontalba', localizada en la Sierra de Guadarrama (N Madrid). Identificamos 12 comunidades vegetales agrupadas en siete grandes tipos de vegetación: 1) Comunidades higrófilas y acuáticas; 2) Prados; 3) Comunidad pionera de suelos alterados; 4) Vegetación herbácea nitrófila de líndero de bosque; 5) Vegetación herbácea de lindero de bosque; 6) Comunidad arbustiva de orla de bosque; y 7) Vegetación forestal. Se señala el interés de la Estación para trabajos de investigación. Su campo de aplicación incluye sucesión primaria, ambientes anfibios, gradientes de humedad del suelo, ecotonos, y ambientes forestales. La Estación Biológica alberga, además, un tipo de hábitat listado en la Directiva 92/43/CEE que corresponde a cursos de agua de llanura o montanos con vegetación de Ranunculion fluitantis y Callitricho-Batrachion (hábitat 3260).

Palabras clave: Actividades de investigación, Comunidades vegetales, Conservación, Gradientes ambientales, Sierra de Guadarrama.

Vegetation composition of the UCM Biological Field Station "Finca de Ontalba"

ABSTRACT

A vegetation study in the Biological Field Station of the Complutense University of Madrid named 'Finca de Ontalba', located in Guadarrama Mountains (North Madrid), was carried out. We identified 12 plant communities grouped in the following seven vegetation types: 1) Hygrophilous and aquatic communities; 2) Meadows; 3) Pioneer community of open disturbed soils; 4) Nitrophilous tall-herb vegetation of forest edge; 5) Forest-edge herbaceous community; 6) Forest-edge scrub community; and 7) Forest vegetation. The interest of the Station for research studies is pointed out. Its scope includes primary succession, amphibious environment, soil moisture gradient, ecotones, and forested environment. Besides, the Biological Station hosts a freshwater habitat type listed in the European Community Directive (92/43/EEC) which corresponds to water courses of plain or montane levels with Ranunculion fluitantis and Callitricho-Batrachion vegetation (habitat code 3260).

Keywords: Conservation, Environmental gradients, Guadarrama Mountains, Plant communities, Research activities.

Composition végétal de la Station Biologique de l' UCM 'Finca de Ontalba'

RÉSUMÉ

Nous avons réalisé une étude sur la végétation de la Station Biologique Complutense, nommée 'Finca de Ontalba', et située dans la Sierra de Guadarrama (N Madrid). Á cet endroit, nous avons identifié 12 communautés végétales regroupées en sept grands types de végétation: 1) Communautés hygrophiles et aquatiques; 2) Prairies; 3) Communautés pionnières des sols perturbés; 4) Végétation herbacée nitrophile de la limite de la forêt; 5) Végétation herbacée des lisières de la forêt; 6) Communauté frontièrienne arbustive de la limite de la forêt; et 7) Végétation forestière. L'intérêt que cette station suscite pour les travaux de recherche est remarquable. Son champ d'application comprend les environnements de succession primaire, les amphibiens, les gradients d'humidité du sol, les écotones et les environnements forestiers. La Station Biologique abrite également un type d'habitat cité dans la directive 92/43/CEE, qui correspond à des cours d'eau de la végétation des plaines ou de montagne avec le Ranunculion fluitantis et le Callitricho-Batrachion (habitat 3260).

Mot clé: Recherche, Communautés végétales, Conservation, Gradients environnementaux, Sierra de Guadarrama.

1. INTRODUCTION

Environmental managements such as fire, grazing, agriculture and plantations modify natural vegetation and landscape (Mooney et al. 1980, Trabaud 1980, Adler et al 2001, Quintana et al. 2004). The Mediterranean region has been under human influence for thousands of years. The landscapes of this part of the world have, therefore, evolved under this constant human impact, environmental impacts of ancient civilisations still being visible (Tzatzanis et al. 2003). The Mediterranean landscape has resulted in a highly differentiated mosaic of semi-natural landscape types (Rackham & Moody 1996). These landscapes include natural habitats meaning terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural (EC 2007). The knowledge of the natural habitats content of any area with environmental interest is essential for its preservation and protection.

Many prestigious universities around the world have associated Biological Field Stations which are used as important tools for research and educational activities (Wilson 1982). These Biological Stations include wild ecosystems providing a place for conservation biodiversity and a setting for short and long-term ecological studies (Eisner 1982). Specifically, studies on their biological content and the ecological processes operating on are essential to know the ecosystem functions. Recently, the 'Finca de Ontalba' (Rascafría, Madrid) has been designed as Biological Station of the Complutense University (http://www.ucm.es/). In this work, we aim to identify the plant-community types occurring in the UCM Biological Station. The results provide knowledge on biological and ecological

values of the Station. Furthermore, vegetation discontinuities help to detect environmental changes and anthropic disturbances.

2. MATERIAL AND METHODS

The UCM Biological Station 'Finca de Ontalba' (50 ha, Paular valley, Rascafría, 1234 m a.s.l., 40°54'N, 3°52'W) is located in the north of Madrid region, in Sierra de Guadarrama. Paular valley is home to considerable plant diversity with 1,378 species and 112 plant-community types (Fernández-González 1988, 1991). Mean annual precipitation is 1,030 mm, and mean annual temperature is 9.8º C. The area has a Supra-submediterranean bioclimate (Rivas-Martínez et al. 2004a) with cold and humid winters (Fernández-González 1988). Soils in the study area correspond to brown soils on silicate rocks (Guerra et al. 1966). The area is located in the Central Sector of the Western Central System with a dominance of Palaeozoic metamorphic gneiss (Bellido et al. 1981). Paular valley remains a Cretaceous-Tertiary sedimentary series partially dismantled and fragmented by the river network, and largely buried under Quaternary deposits, both fluvial and fluvioglacial. Biogeographically, the territory is included in the Carpetano-Leonese Sector, Mediterranean West Iberian Province, Mediterranean Region (Rivas-Martínez et al. 2004b). The natural potential vegetation consists of Pyrenean oak (*Quercus pyrenaica*) forests (Rivas-Martínez 1987). The area has been widely subjected to Scots pine plantations (*Pinus sylvestris* var. *iberica*) which has resulted in forested areas with pine and oak (Rivas-Martínez & Cantó 1987, Cañellas et al. 2000).

Field work was carried out during the spring and summer 2009 and 2010. Vegetation sampling was performed according to the phytosociological method (Braun-Blanquet 1979). Sampling plots (relevés) were made in areas with homogeneous vegetation, according to growth forms and physiognomic-ecological plant formations (Mueller-Dombois & Ellenberg 1974). Relevés were gathered in detailed phytosociological tables (not shown) by means of floristic similarities. Table sorting was used to detect and characterize vegetation types. Plant-communities were assigned to phytosociological syntaxa according to Rivas-Martínez et al. (2001). Plant nomenclature is according to Flora iberica (Castroviejo et al. 1986-2012) and Flora Europaea (Tutin et al. 1964-1980). Identification of human activities has been based on field observations, bibliographic references, and maintenance personnel communications.

3. RESULTS AND DISCUSSION

3.1 VEGETATION DESCRIPTION

In the Biological Field Station we identified 12 community types (Table 1) which we have grouped in seven vegetation groups.

1. HYGROPHILOUS AND AQUATIC COMMUNITIES

Three hygrophilous communities and two aquatic communities, all of them with a scarce distribution in the studied area, were identified. The helophytic community dominated by the tall herb *Oenanthe crocata* was found in the bed of temporary streams. This community is ascribed to the Atlantic-Mediterranean association Glycerio declinatae-Oenanthetum crocatae (Molina & Moreno 1999). Low water margin vegetation was also indentified in the spring from which the Finca takes its name, Fuente Alba. On coarse sandy soil margins the vegetation is dominated by *Veronica anagallis-aquatica*, whereas on silty soil margins the vegetation is presided by Myosotis stoloniferа. We ascribe the former to Glycerio declinatae-Apietum nodiflori association (Molina 1996) and the later to Myosotidetum stoloniferae association (Molina 2001).

We recognized two water-plant communities according to water flow: the lotic community of Ranunculus pseudofluitans, restricted to the sand bed of La Yesera stream in the eastern part of the Station; and the lentic community of Ranunculus peltatus, found in some pools of doline origin. The first community is ascribed to Callitricho brutiae-Ranunculetum pseudofluitantis association and the second to Callitricho brutiae-Ranunculetum peltati association (Rivas-Martínez et al. 2001).

2. MEADOWS

We recognized two types of meadows along a soil moisture gradient. The Agrostis castellana meadow, "vallicar", which occupy seasonally, wet soils with a pronounced summer drying. They correspond to the phytosociological association Festuco amplae-Agrostietum castellanae. The *Cynosurus cristatus* meadow is developed in seasonally wet soils for extended periods. It is ascribed to Festuco amplae-Cynosuretum cristati association.

3. PIONEER COMMUNITY OF OPEN DISTURBED SOILS

We found a community characterized by the moss *Funaria hygrometrica* colonizing recent fire areas resulting from the slash-pile prescribed burns. This type of burns is a common forest management procedure in Guadarrama Mountains in order to control tree growth and insect pests (Montero González et al. 2001, Castoldi 2009). We do not know the syntaxonomical place of this community.

4. NITROPHILOUS TALL-HERB VEGETATION OF FOREST EDGE

In semi-shaded nutrient-rich soils of forest edge a forb community with the following characteristic species was found: *Alliaria petiolata, Lapsana communis, Myrrhoides nodosa,* and *Galium aparine*. We ascribe this community to Myrrhoidi nodosae-Alliarietum petiolatae association.

5. FOREST-EDGE HERBACEOUS COMMUNITY

Vegetation consisted of perennial forbs occupying a narrow, semi-shaded fringe between forests and neighbouring meadows. It is well characterized in the area by *Vicia tenuifolia, Trifolium ochroleucon*, and *Tanacetum corymbosum*, among others species. We ascribe this community to Trifolio medii-Lathyretum nigri association.

6. SCRUB COMMUNITY OF FOREST EDGE

A community dominated by thorny and spiny shrubs occurs at the forest edge, especially when the forest is managed to favour meadows. This community develops on well structured and deep soils and includes as characteristic species in the area *Prunus spinosa, Crataegus monogyna, Rosa canina,* and *Adenocarpus complicatus*. It corresponds to the Rubo ulmifolii-Rosetum corymbiferae association (Fernández-González 1991).

7. FOREST VEGETATION

As consequence of past and current management which includes plantation of Scots pines and clearing of Pyrenean oaks, mixed stands of both trees are the main components of the forest landscape (Castoldi 2009). The understory is rich in herbs such as *Arenaria montana, Primula veris, Prunella grandiflora, Viola riviniana, Veronica officinalis*, and *Pteridium aquilinum*, among others species. In the Station, Pinus sylvestris trees reach a greater height (22 m height and 41 cm dbh on average) than *Quercus pyrenaica* trees (7 m height and 7 cm dbh on average). Only one oak was found with 14 m height and 44 cm dbh.

Table 1. Plant community types in the UCM Biological Field Station 'Finca de Ontalba'

Vegetation description	Association
Riparian tall-helophytic forbs of *Oenanthe crocata*	Glycerio declinatae-Oenanthetum crocatae
Low-helophytic forbs of *Veronica anagallis-aquatica*	Glycerio declinatae-Apietum nodiflori
Low-helophytic forbs of *Myosotis stolonifera*	Myosotidetum stoloniferae
Hydrophytic vegetation of lotic waters of *Ranunculus pseudofluitans*	Callitricho brutiae-Ranunculetum pseudo-fluitantis
Hydrophytic vegetation of lentic waters of *Ranunculus peltatus*	Callitricho brutiae-Ranunculetum peltati
Meadows of *Agrostis castellana*	Festuco amplae-Agrostietum castellanae
Meadows of *Cynosurus cristatus*	Festuco amplae-Cynosuretum cristat
Community of *Funaria hygrometrica*	——————————-
Nitrophilous forbs of forest edge	Myrrhoidi nodosae-Alliarietum petiolatae
Herbaceous edge forest vegetation	Trifolio medii-Lathyretum nigri
Spiny scrubs of forest edge	Rubo ulmifolii-Rosetum corymbiferae
Forest vegetation of *Pinus sylvestris* and *Quercus pyrenaica*	Luzulo forsteri-Quercetum pyrenaicae

3.2 HABITATS VALUE

In the Station, primary succession can be studied in two contrasting habitats. The habitat defined by Glycerio declinatae-Oenanthetum crocatae corresponds to tall-forb vegetation of shallow water in temporary streams where the stages of primary succession can be observed on alluvial soils in a riparian environment (Molina &

Moreno 1999). The habitat, designed here as Community of *Funaria hygrometrica*, belongs to plant succession early stages after slash-pile prescribed burns. Primary succession can be studied, in this case, on ash-rich soils in a forest environment (Delasheras et al. 1994).

Spring habitats constituted by communities of *Myosostis stolonifera* or *Veronica anagallis-aquatica* in the territory are characterized by permanently or semi- permanently flooded soils, and acid waters that flow at a relatively constant rate and cold temperature throughout the year. These habitats more resilient to variation in precipitation and climate change than surface run-off watersheds (Jeffres et al. 2009).

Aquatic habitats found in the territory are part of lotic (Callitricho brutiae-Ranunculetum pseudofluitantis) or lentic (Callitricho brutiae-Ranunculetum peltati) ecosystems. The former is listed in the Directive Habitat (92/43/EEC) as 'water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion' (habitat code 3260). The habitat Directive forms the cornerstone of Europe's nature conservation policy (CE 2007).

The meadows identified in the Station are related to a hydric gradient. Soil moisture regime defines the existence of Festuco amplae-Agrostietum castellanae or Festuco amplae-Cynosuretum cristati in wet soils according to longer or shorter seasonally drying conditions, respectively. This gradient allows studying the incidence of dry or humid period on the balance. Furthermore, grazing and harvesting managements increase meadow type and richness (Fernández-González 1988, Rodríguez-Rojo & Sánchez-Mata 2004). Studies about their relationships are important for future management plans which should preserve these uses in order to maintain biodiversity of grasslands.

We recognized three ecotone-habitats, two defined by herbaceous plant-communities (Myrrhoidi nodosae-Alliarietum petiolatae, Trifolio medii-Lathyretum nigri) and one by shrubby vegetation (Rubo ulmifolii-Rosetum corymbiferae). The knowledge of border zone function has important implications in terms of forests conservation and regeneration (López-Barrera 2004).

Oak woods of *Quercus pyrenaica* are listed in the Directive Habitat (92/43/EEC), as natural habitat type of European community interest for conservation (habitat code 9230). This is the natural potential vegetation of the area (Luzulo forsteri-Quercetum pyrenaicae, Rivas-Martínez 1987). However, Finca de Ontalba is mainly cover by a mixed pine-oak forest as the result of systematic *Pinus sylvestris* plantation for timber production, while young *Quercus pyrenaica* stands are recovering from intensive grazing and cutting. Since Quercus pyrenaica forests show a depressed regeneration at least in the past three decades (Barbour et al. 2007) and since they are sensitive to drier conditions caused by climate change (Hernández-Santana et al. 2009), the favouring of *Quercus pyrenaica* stands is important for European biodiversity conservation.

Past and current management of the territory include pine plantation, prescribed burns, charcoal production, clay mining, watercourses diversion, cattle and horse grazing. Investigating the relationships between these activities and vegetation res-

ponse is crucial to understand the current plant-landscape and the major driving environmental factors. Furthermore, it can help to forecast future plant-landscape in a global change scenario.

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II.

Flora de la Estación Biológica UCM ‘Finca de Ontalba’

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Flora de la Estación Biológica UCM "Finca de Ontalba"

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Introducción

Muchas universidades en todo el mundo tienen estaciones biológicas asociadas, las cuales constituyen herramientas importantes para desarrollar actividades tanto docentes como de investigación en campo (Eisner 1982). Las estaciones biológicas son laboratorios localizados en la naturaleza con una biota y un conjunto de hábitats característicos que se prestan a estudios específicos y multidisciplinares (Brussard 1982, Ginetsinskaja 1995). Estos pueden incluir trabajos relacionados con cualquier aspecto de la flora y fauna local, su biología y ecología (Tellería 2007). Además, las estaciones biológicas son lugares idóneos para llevar a cabo experimentos de campo a largo plazo. Desde 2007, la Universidad Complutense de Madrid ha incorporado como Estación Biológica un terreno de unas 50 hectáreas en la sierra de Madrid conocido como Finca de Ontalba (Figura 1).

Ontalba se encuentra ubicada en el valle del Paular (Rascafría, Madrid, 40° 54'N, 3° 52'O) dentro de las estribaciones meridionales de la Sierra de Guadarrama, a unos 1.200 m de altitud (Figura 1). Desde un punto de vista litológico, los suelos se desarrollan fundamentalmente sobre gneis glandular. Las calizas cretácicas que se conservan en la fosa del Lozoya, en gran parte enterradas bajo depósitos cuaternarios, afloran en cursos de aguas o manifiestan su morfología kárstica en forma de dolinas (Arenas et al. 1991).

De acuerdo con los datos meteorológicos de la estación climática más cercana con datos significativos (Rascafría), la precipitación media anual en el territorio es de unos 1.000 mm y la temperatura media anual de unos 10ºC. La Estación Biológica Ontalba se sitúa en un territorio con bioclima Templado oceánico dentro

de la variante submediterránea (Rivas-Martínez et al. 2004a). Desde un punto de vista biogeográfico, el territorio se encuentra incluido en la provincia Carpetano-Leonesa de la región Mediterránea (Rivas-Martínez et al. 2004b). La vegetación potencial del área de estudio corresponde a un melojar subhúmedo silicícola de la asociación *Luzulo forsteri-Quercetum pyrenaicae* (Rivas-Martínez 1982, Fernández-González 1991). En suelos más húmedos la vegetación potencial corresponde a un melojar-fresneda de la asociación *Querco pyrenaicae-Fraxinetum angustifoliae* (Figura 1). El paisaje vegetal actual de la finca está constituido principalmente por un ecosistema forestal en el que se entremezcla el roble melojo (*Quercus pyrenaica* Willd.) con el pino albar (*Pinus sylvestris* L.) -Castoldi & Molina 2012-. Una extensión bastante menor está ocupada por pastos fundamentalmente de *Agrostis castellana* (vallicares). El territorio ha sido sometido a diferentes manejos entre los que destacan el pastoreo de ganado, la entresaca del pino silvestre y las quemas controladas para el saneamiento del bosque o para la producción de carbón.

Las estaciones biológicas deben asumir un papel activo en la conservación de la diversidad de las especies (Brussard 1982). Para ello se precisa, en primer lugar, conocer su contenido biológico. El objetivo principal de este trabajo consiste en aportar un listado de la flora vascular de la Estación Biológica UCM "Finca de Ontalba". Los resultados permitirán conocer el valor florístico de la estación con respecto al valle del Paular. Estos datos pueden ser especialmente valiosos ya que este valle forma parte de la zona periférica de protección del Parque Nacional de Peñalara (www.parquenaturalpenalara.org).

Métodos y nomenclatura

El trabajo de campo se llevó a cabo entre marzo de 2009 y septiembre de 2013 que corresponde al período fenológico más favorable de la mayoría de las plantas. Se llevaron a cabo numerosas rutas aleatorias dentro de la finca con el objeto de encontrar todas las especies presentes. Con la excepción de las especies raras o amenazadas de las que sólo se tomaron fotografías, del resto de plantas se recogieron ejemplares con los que se confeccionaron pliegos testigos que se conservan en el

Herbario MAF (Facultad de Farmacia, UCM). La nomenclatura de los taxones está de acuerdo con Castroviejo et al. (1986-2012) o con Tutin et al. (1964-1980).

Figura 1. Paisajes vegetales característicos de la Finca de Ontalba. a) robledal con sotobosque de *Pteridium aquilinum*; b) aspecto del bosque con dominancia de *Pinus sylvestris*; c) pastos con *Cynosurus cristatus*; d) dolina; e) quemas controladas de restos vegetales.

Catálogo florístico

Achillea millefolium L. subsp. *millefolium*

Acinos alpinus (L.) Moench

Adenocarpus complicatus (L.) A. Gay

Agrostis castellana Boiss. & Reuter

Aira caryophyllea L. subsp. *caryophyllea*

Allium guttatum Steven subsp. *sardoum* (Moris) Stearn

Alyssum minutum DC.

Alopecurus arundinaceus Poir.

Anacamptis coriophora (L.) R.M.Bateman, Pridgeon & M.W.Chase

Anacamptis morio (L.) R.M. Bateman, Pridgeon & M.W. Chase

Andryala integrifolia L.

Anthemis arvensis L.

Anthoxanthum aristatum Boiss. subsp. *aristatum*

Anthoxanthum odoratum L.

Anthriscus sylvestris (L.) Hoffm.

Apium nodiflorum (L.) Lag.

Aquilegia vulgaris L. subsp. *hispanica* (Willk.) Heywood

Arabis glabra (L.) Bernh.

Arenaria montana L. subsp. *montana*

Arenaria serpyllifolia L.

Aristolochia paucinervis Pomel

Armeria arenaria (Pers.) Schult. subsp. *segoviensis* (Gand. ex Bernis) Nieto Fel.

Arrhenatherum elatius (L.) Beauv. ex J. & C. Presl subsp. *bulbosum* Schübler & Martens

Asphodelus albus Mill. subsp. *carpetanus* Z. Díaz & Valdés

Astragalus glycyphyllos L.

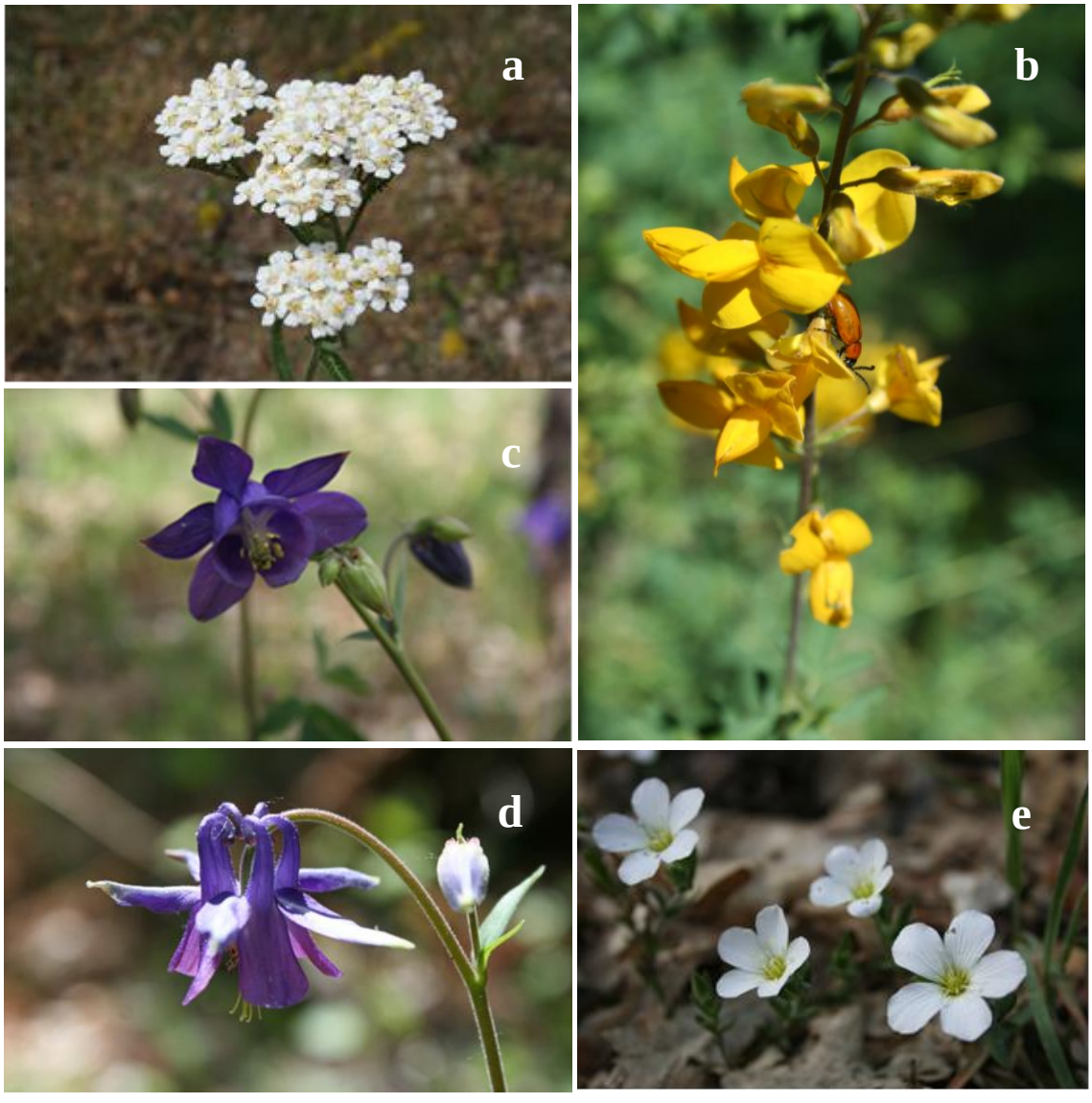

Fig. 2. a) *Achillea millefolium* L. subsp. *millefolium*; b) *Adenocarpus complicatus*; c) y d) *Aquilegia vulgaris* subsp. *hispanica*; e) *Arenaria montana* subsp. *montana*.

Fig. 3. a) *Anacamptis coriophora*; b) *Anacamptis morio*; c) *Athyrium filix-femina*; d) *Asphodelus albus* subsp. *carpetanus*.

Astragalus incanus L. subsp. *nummularioides* (Desf.) Maire

Athyrium filix-femina (L.) Roth

Avenella flexuosa (L.) Drejer subsp. *iberica* (Rivas Mart.) Valdés & H. Scholz

Avenula sulcata (Gay ex Boiss.) Dumort. subsp. *sulcata*

Ballota nigra L.

Barbarea intermedia Boreau

Bellis perennis L.

Bellis sylvestris Cyr.

Brachypodium pinnatum (L.) Beuv. subsp. *rupestre* (Host) Schübler & Martens

Brachypodium sylvaticum (Hudson) Beauv.

Briza media L. subsp. *media*

Bromus hordeaceus L.

Bromus racemosus L.

Bromus sterilis L.

Callitriche brutia Petagna

Calluna vulgaris (L.) Hull

Campanula rapunculus L.

Capsella bursa-pastoris (L.) Medik.

Cardamine hirsuta L.

Cardamine pratensis L. subsp. *pratensis*

Carex binervis Sm.

Carex caryophyllea Latourr.

Carex divulsa Stokes

Carex flacca Schreb.

Carex leporina L.

Carex muricata L. subsp. *pairae* (F.W. Schultz) Čelak.

Carex panicea L.

Carlina vulgaris L. subsp. *spinosa* (Velen.) Vandas

Carum verticillatum (L.) W.D.J. Koch

Centaurium pulchellum (Sw.) Druce

Centaurea graminifolia (Lam.) Muñoz Rodr. & Devesa

Centaurea nigra L. subsp. *carpetana* (Boiss. & Reuter) Nyman

Centaurea ornata Willd.

Cerastium fontanum Baumg. subsp. *vulgare* (Hartm.) Greuter & Burdet

Cerastium glomeratum Thuill.

Cerastium semidecandrum L.

Cirsium arvense (L.) Scop.

Cirsium palustre (L.) Scop.

Cirsium pyrenaicum (Jacq.) All.

Cirsium vulgare (Savi) Ten.

Clinopodium vulgare L.

Conopodium pyrenaeum (Loisel.) Miégev.

Convolvulus arvensis L.

Crataegus monogyna Jacq.

Crocus serotinus Salisb. subsp. *salzmannii* (J. Gay) B. Mathew

Cruciata glabra (L.) Ehrend. subsp. *hirticaulis* (Beck) Natali & Jeanm.

Cruciata laevipes Opiz

Crucianella angustifolia L.

Cynosurus cristatus L.

Cynosurus echinatus L.

Cynosurus effusus Link

Cytisus scoparius (L.) Link

Dactylis glomerata L.

Dactylorhiza elata (Poir.) Soó

Danthonia decumbens (L.) DC.

Deschampsia cespitosa (L.) P. Beav. subsp. *hispanica* Vivant

Dianthus armeria L. subsp. *armeria*

Dianthus deltoides L. subsp. *deltoides*

Doronicum plantagineum L.

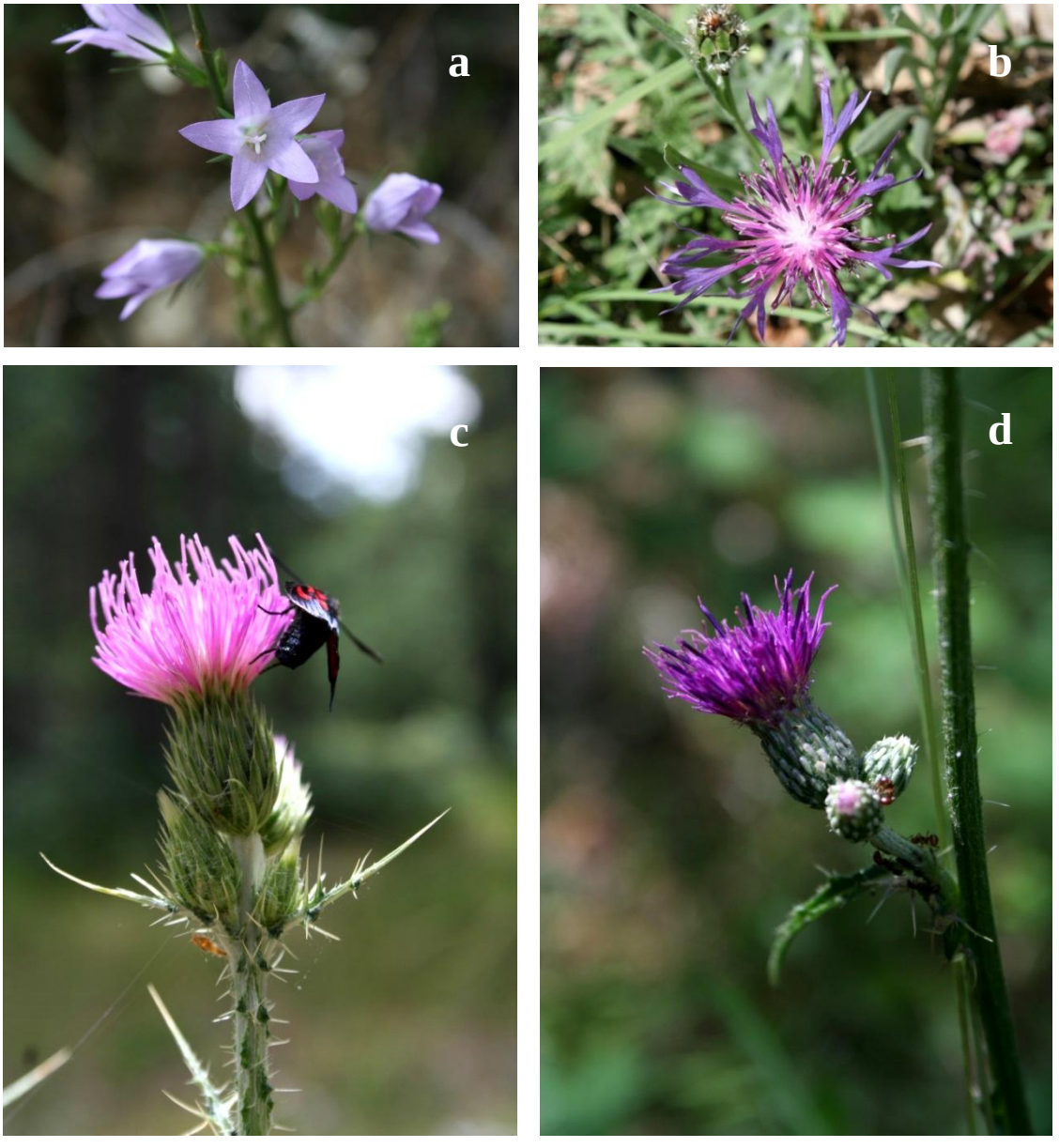

Fig. 4. a) *Campanula rapunculus*; b) *Centaurea graminifolia*; c) *Cirsium* arvense; d) *Cirsium palustre*.

Fig. 5. a) *Crataegus monogyna*; b) *Cruciata laevipes*; c) *Cytisus scoparius*; d) *Dactylorhiza*

elata; e) *Doronicum plantagineum*; f) *Eleocharis palustris* subsp. *vulgaris*.

Echium vulgare L. subsp. *vulgare*

Eleocharis palustris (L.) Roem. & Schult. subsp. *vulgaris* Walters

Elymus caninus (L.) L.

Epilobium lanceolatum Sebast. & Mauri

Epilobium obscurum Schreb.

Epilobium tetragonum L. subsp. *tetragonum*

Equisetum arvense L.

Erica arborea L.

Erophila verna (L.) Chevall.

Eryngium campestre L.

Euonymus europaeus L.

Euphorbia angulata Jacq.

Evax lasiocarpa Lange ex Cutanda

Festuca durandoi Clauson subsp. *livida* (Hack.) Rivas Ponce & Cebolla

Festuca rothmaleri (Litard.) Markgr.-Dannenb.

Festuca rubra L.

Festuca rivas-martinez Fuente & Ortúñez subsp. *rivas-martinez*

Filipendula vulgaris Moench

Fragaria vesca L.

Fraxinus angustifolia Vahl

Galium aparine L.

Galium palustre L.

Galium parisiense L. subsp. *divaricatum* (Pourr. ex Lam.) Rouy & E.G. Camus

Galium rotundifolium L.

Galium verum L. subsp. *verum*

Genista florida L.

Geranium columbinum L.

Geranium dissectum L.

Geranium pyrenaicum Burm. f. subsp. *lusitanicum* (Samp.) S. Ortíz

Geranium robertianum L.

Fig. 6. a) *Filipendula vulgaris*; b) *Galium palustre*; c) *Geum sylvaticum*; d)*Geranium robertianum.*

Geranium sanguineum L.

Geum sylvaticum Pourr.

Geum urbanum L.

Gladiolus illyricus Koch

Hedera helix L.

Helianthemum apenninum (L.) Mill. subsp. *apenninum*

Herniaria glabra L.

Herniaria lusitanica Chaudhri subsp. *lusitanica*

Hieracium pilosella L.

Holcus lanatus L. subsp. *lanatus*

Hordeum murinum L. subsp. *murinum*

Hyacinthoides hispanica (Mill.) Rothm.

Hypericum humifusum L.

Hypericum montanum L.

Hypericum perforatum L.

Hypochaeris radicata L.

Ilex aquifolium L.

Isolepis setacea (L.) R. Br.

Jasione montana L.

Juncus acutiflorus Ehrh. ex Hoffm.

Juncus bulbosus L.

Juncus bufonius L.

Juncus effusus L.

Juncus inflexus L.

Juncus squarrosus L.

Juncus tenageia Ehrh. ex L.

Juniperus communis L. subsp. *hemisphaerica* (C. Presl) Nyman

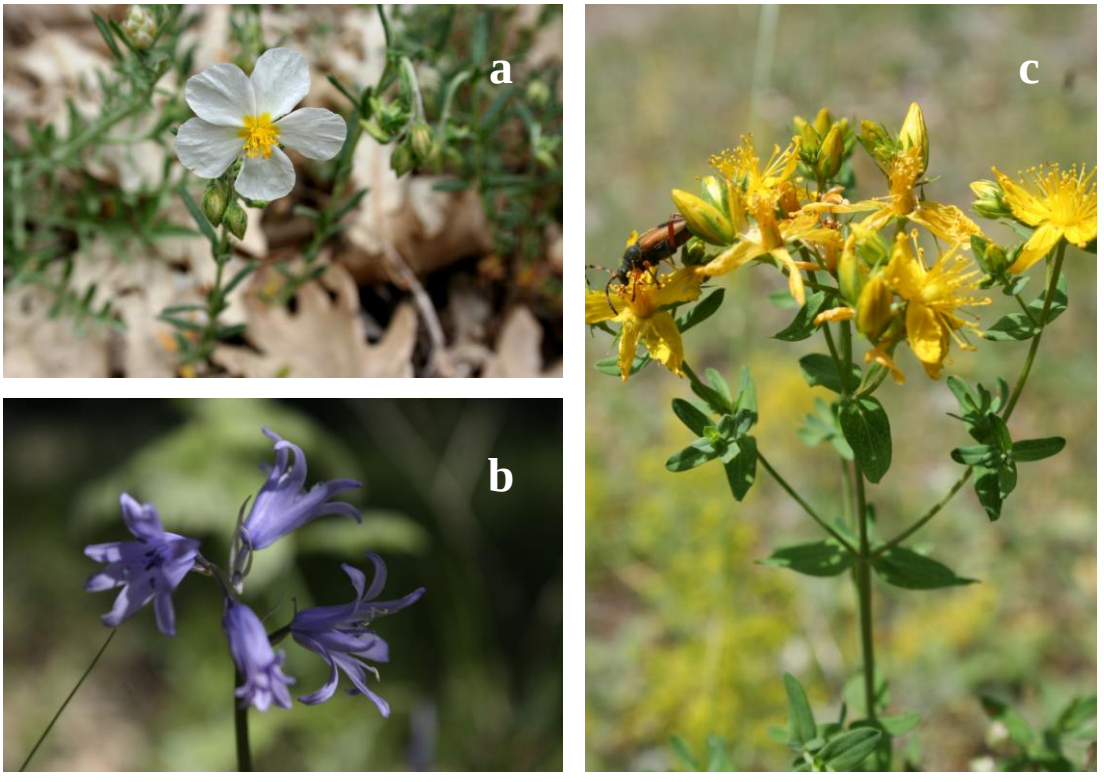

Fig. 7. a) *Helianthemum apenninum* subsp. *apenninum*; b) *Hyacinthoides hispanica*; c) *Hypericum perforatum*.

Lactuca virosa L.

Lamium hybridum Vill.

Lapsana communis L. *communis*

Lathyrus linifolius (Reichard) Bässler

Lathyrus nissolia L.

Lathyrus pratensis L.

Lathyrus sphaericus Retz.

Lepidium heterophyllum Benth.

Ligustrum vulgare L.

Lilium martagon L.

Linum catharticum L.

Lolium rigidum Gaudin

Logfia minima (Sm.) Dumort.

Lonicera periclymenum L. subsp. *hispanica* (Boiss. & Reuter) Nyman

Lotus corniculatus L. subsp. *carpetanus* (Lacaita) Rivas Mart.

Lotus corniculatus L. subsp. *corniculatus*

Luzula campestris (L.) DC.

Luzula forsteri (Sm.) Lam. & DC. subsp. *forsteri*

Malus sylvestris (L.) Mill.

Medicago lupulina L.

Melampyrum pratense L.

Melampyrum pratense Retz.

Mentha longifolia (L.) Huds.

Mentha suaveolens Ehrh.

Merendera montana (Loefl. ex L.) Lange

Milium vernale Bieb.

Molineriella laevis (Brot.) Rouy

Monotropa hypopitys L.

Montia fontana L.

Mycelis muralis (L.) Dumort.

Myosotis arvensis (L.) Hill subsp. *Arvensis*

*Myososti*s *discolor* Pers.

Myosotis secunda Al. Murray

Narcissus bulbocodium L.

Nardus stricta L.

Nasturtium officinale R. Br.

Neottia nidus-avis (L.) Rich.


a


b


c


d


e


f

Figura 8. a) *Lathyrus linifolius*; b) *Melica uniflora*; c) *Neottia nidus-avis*; d) *Melampyrum pratense*; e) *Narcissus bulbocodium*; f) *Mentha longifolia*.

Oenanthe crocata L.

Ornithogalum bourgaeanum Jord. & Fourr.

Ornithopus compressus L.

Ornithopus perpusillus L.

Origanum vulgare L. subsp. *virens* (Hoffmans. & Link) Bonnier & Layens

Pentaglottis sempervirens (L.) Tausch

Petrorhagia nanteuilii (Burnat) P.W. Ball & Heywood

Phleum pratense L. subsp. *bertolonii* (DC.) Bornm.

Pinus sylvestris L.

Plantago coronopus L.

Plantago holosteum Scop.

Plantago lanceolata L.

Plantago major L.

Plantago media L.

Poa annua L.

Poa bulbosa L.

Poa nemoralis L.

Poa pratensis L.

Poa trivialis L.

Polygala vulgaris L.

Polygonatum odoratum Miller

Populus tremula L.

Potentilla argentea L.

Potentilla asturica Rothm.

Potentilla erecta (L.) Raeusch.

Potentilla neumanniana Rchb.

Potentilla reptans L.

Primula veris L. subsp. *veris*

Prunella grandiflora (L.) Scholler

Prunella laciniata L.

Prunella vulgaris L.

Prunus padus L.

Prunus spinosa L.

Pteridium aquilinum (L.) Kuhn.

Quercus pyrenaica Willd.

Fig. 9. a) *Pentaglottis sempervirens*; b) *Poa bulbosa*; c) *Primula veris* subsp. *veris*.

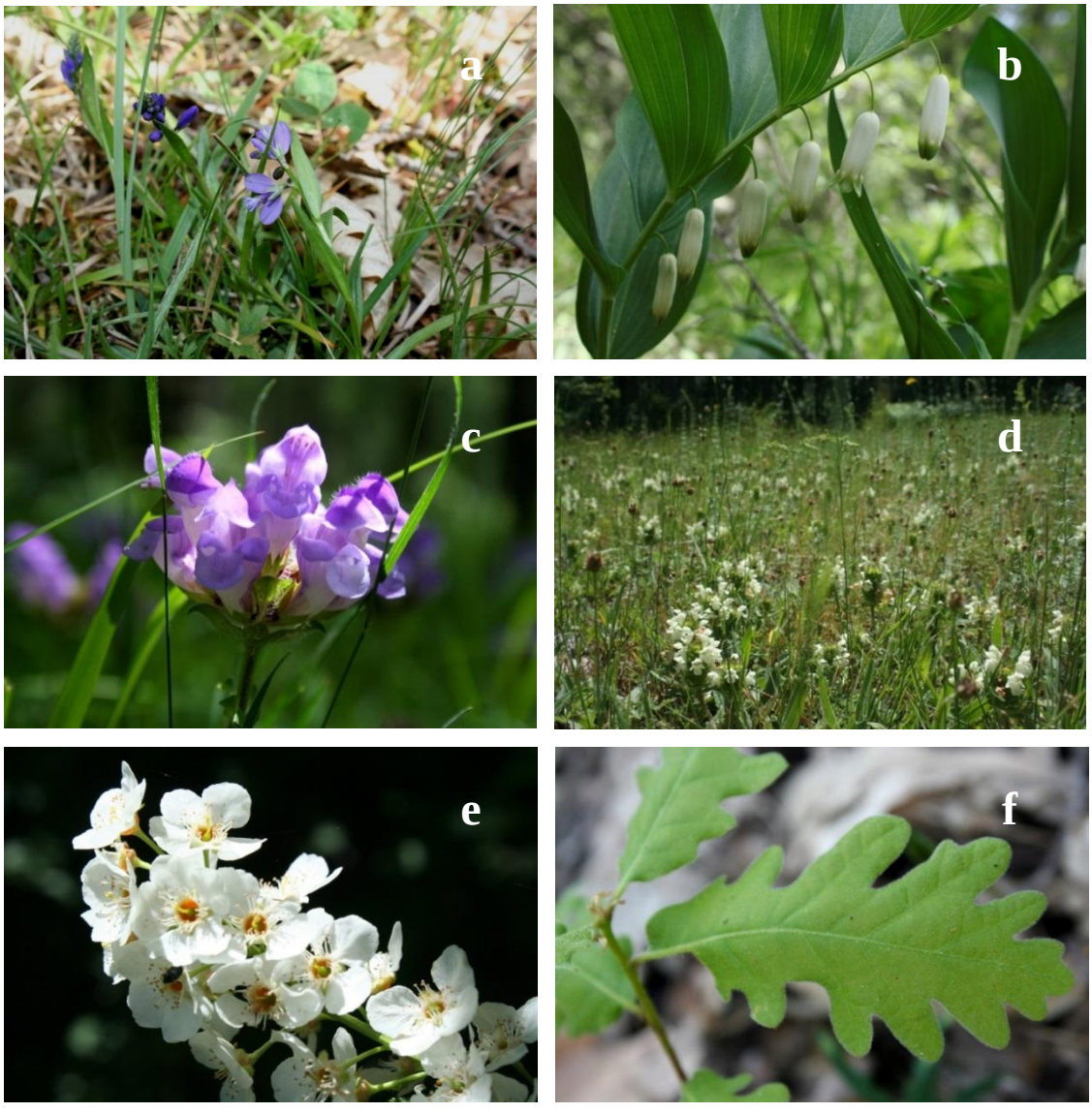

Fig. 10 a) *Polygala vulgaris*; b) *Polygonatum odoratum*; c) *Prunella grandiflora*; d) *Prunella laciniata*; e) *Prunus padus* ; f) *Quercus pyrenaica*.

Ranunculus bulbosus L. subsp. *aleae* (Willk.) Rouy & Foucaud

Ranunculus nodiflorus L.

Ranunculus ollisiponensis Pers. subsp. *ollisiponensis*

Ranunculus paludosus Poir.

Ranunculus peltatus Schrank

Ranunculus repens L.

Ranunculus valdesii Grau

Rhamnus cathartica L.

Rorippa pyrenaica (All.) Rchb.

Rosa canina L.

Rubus castellarnaui Pau

Fig. 11. *Ranunculus valdesii*

Rubus lainzii H.E. Webber

Rubus ulmifolius Schott

Rumex acetosella L. subsp. *angiocarpus* (Murb.) Murb.

Rumex acetosa L. subsp. *acetosa*

Salix alba L.

Salix atrocinerea Brot.

Salvia verbenaca L.

Sanguisorba minor Scop. subsp. *minor*

Sanicula europea L.

Saxifraga granulata L.

Scabiosa columbaria L. subsp. *columbaria*

Scleranthus annuus L.

Sedum forsterianum Sm.

Sedum maireanum Sennen

Senecio jacobea L.

Serapias lingua L.

Silene latifolia Poir.

Silene nutans L. subsp. *nutans*

Sorbus latifolia (Lam.) Pers.

Stachys officinalis (L.) Trevisan

Stellaria graminea L.

Succisa pratensis Moench


a


b


c


d


e


f

Fig. 12. a) *Sanicula europea*; b) *Sedum forsterianum*; c) *Sedum maireanum*; d) *Sorbus latifolia*; e) *Silene nutans* subsp. *nutans*; f) *Stachys officinalis*.

Tanacetum corymbosum (L.) Schultz subsp. *corymbosum*

Teesdalia nudicaulis (L.) R. Br.

Teucrium scorodonia L.

Thapsia villosa L.

Thymus pulegioides L.

Torilis japonica (Houtt.) DC.

Trifolium arvense L.

Trifolium campestre Shreb.

Trifolium dubium Sibth.

Trifolium glomeratum L.

Trifolium pratense L. subsp. *pratense*

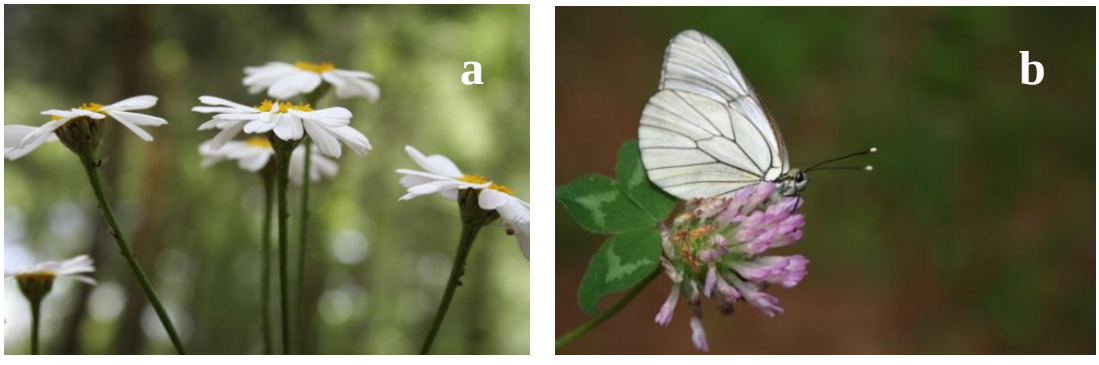

Fig. 13. a) *Tanacetum corymbosum* subsp. *corymbosum*; b) *Trifolium pratense* subsp. *pratense*.

Trifolium repens L.

Trifolium striatum L. subsp. *striatum*

Trifolium strictum L.

Trisetum flavescens (L.) Beauv. subsp. *flavescens*

Urtica dioica L

Valerianella locusta (L.) Laterr. subsp. *locusta*

Verbascum pulverulentum Vill.

Veronica anagallis-aquatica L. subsp. *anagallis-aquatica*

Veronica arvensis L.

Veronica beccabunga L. subsp. *beccabunga*

Veronica chamaedrys L. subsp. *chamaedrys*

Veronica hederifolia L.

Veronica officinalis L.

Veronica serpyllifolia L. subsp. *serpyllifolia*

Vicia angustifolia L.

Vicia hirsuta (L.) Gray

Vicia sepium L.

Vicia tenuifolia Roth

Vicia tetrasperma (L.) Shreb.

Viola kitaibeliana Schult. in Roem. & Schult.

Viola riviniana Rchb.

Viola suavis M. Bieb.

Vulpia myuros (L.) C.C. Gmelin

Fig. 14. a) *Teucrium scorodonia*; b) *Veronica anagallis-aquatica* subsp. *anagallis-aquatica*; c) *Veronica chamaedrys* subsp. *chamaedrys*.

Resumen y conclusiones

En la Estación Biológica UCM Finca de Ontalba se han identificado 280 plantas vasculares. Teniendo en cuenta que el valle del Paular con una extensión aproximada de 400 km^2 y un desnivel de unos 1200 m, cuenta con 1.378 taxones vegetales (Fernández-González 1988), la flora de Ontalba corresponde casi al 21% de la flora reconocida en el valle. De ello se infiere que la finca de Ontalba, a pesar de representar un 0.125% de la extensión del territorio del valle del Paular, incluye casi un cuarto de su diversidad florística. Esto se puede explicar por la alta riqueza vegetal que presentan los bosques subhúmedos de *Quercus pyrenaica* en comparación con otros ecosistemas forestales (Fernández-González 1991).

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Apéndice 1

Plantas de interés para la conservación de la Estación Biológica de la Universidad Complutense

Apéndice 1

Plants of conservation interest in the Biological Field Station of the Complutense University

Plantas de interés para la conservación de la Estación Biológica de la Universidad Complutense

Biological Stations associated with Universities provide a natural place for carrying out both research and educational activities (Ginetsinskaja 1995). Besides, they supply areas of biodiversity conservation (Eisner 1982). UCM Biological Station (UCM-BS) is located close to Rascafria village (1200 m a.s.l., 40°54'N, 3°52'W, Madrid Region) and it is incuded in the periferic zone of protection of the National Park Sierra de Guadarrama. Plant landscape mainly consists of a managed mixed forest of melojo oak (*Quercus pyrenaica* Willd.) and Scots pine (*Pinus sylvestris* L.).

Two natural habitat type of European community interest for conservation (92/43/EEC) were indentified in the UCM-BS (Castoldi & Molina 2012): oak woods of *Quercus pyrenaica* (habitat code 9230) and water courses of plain or montane levels with *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation (habitat code 3260). 280 plant species were identified in the UCM-BS but their conservation interest is unknown. We aimed to detect the species whose protection requires specific action by the correspondent administration present in the Biological Station based on the protection degree kept in the Madrid regional legislation (Decree 18/1992).

We found seven species of conservation interest in the Province of Madrid. They are the following: *Ilex aquifolium* L., *Lilium martagon* L., *Malus sylvestris* (L.) Mill., *Prunus padus* (L.), *Sorbus latifolia* (Lam.) Pers. and *Taxus baccata* L. (Table 1). *Ilex aquifolium*) is found sparse in the UCM-BS in shrubby and arboreous common form. It is generally scarce in the Central and Southern Mediterranean areas of the

Iberian Peninsula, where it occurs at the Southern limit of its distribution and it is associated with wet montane conditions (Oria de Rueda 1992, Costa et al. 1997). Only three individuals growing together of *Lilium martagon* were found. They have not been seen fruitful as they are affected by the time of flowering by a pest. This species is the most widely distributed of all European lilies and the most common lily species in Europe but in the Madrid Province is threatened by the habitat reduction. One individual of wild apple (*Malus sylvestris*) was found isolated. Its natural regeneration is endangered by grazing and the hybridization with cultivated forms of cherry, apple or pear is a main obstacle. Moreover, several diseases, especially viral diseases, have contaminated the three wild fruit tree species and may endanger their existence in some areas (Kleinschmit and Stephan 1998). Intensive conservation measures are still lacking in all European countries with the exception of Germany, where programmes concentrate on seed orchard establishment have been carried out for several years. Few individuals of *Prunus padus* was found concentrated in a *Agrostis castellana* meadow margin. One isolated individual of *Sorbus latifolia* was found in the UCM-BS. It is also an endangered species but a single individual is able to generate viable seeds and its ornitocora dispersion, especially in autumn, coincides with the passage of migratory birds (Baonza 2004). *Taxus baccata* in the area is isolated and rare. Its threat is not as acute as for the other mentioned species but it is known as a relicts from earlier climatic periods or species situated on the margin of their distribution area (Šatović 2002). Besides the above mentioned species, it is worth noting the scarce presence in the UCM.BS of the Iberian endemic *Ranunculus valdesii* known so far only by collecting a specimen that was used to describe (Valdés and Lopez 1977). It is necessary to consider a conservation program about the seven plants of conservation interest found in Ontalba, in order to preserve them in their natural habitat. The biological station is an optimal opportunity for biological conservation *in situ*.

Table 1: Species whose protection requires specific action by the correspondent administration based on the Madrid regional legislation (Decree 18/1992).

Species	**Conservation status**
Ilex aquifolium L.	Sensitive to habitat disturbance
Lilium martagon L.	Sensitive to habitat disturbance
Malus sylvestris Miller	Special interest
Prunus padus L.	Vulnerable
Ranunculus valdesii Grau	Vulnerable
Sorbus latifolia (Lam.) Pers.	Sensitive to habitat disturbance
Taxus baccata L.	Sensitive to habitat disturbance

SECCIÓN 2

Respuesta de la vegetación tras quemas controladas de residuos de corta en un bosque mixto sub-Mediterráneo

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Vegetation response to slash-pile burning management in a Sub-Mediterranean mixed forest

III.

Efecto de la masa de semillas y del número de cotiledones en la germinación de la semilla de *Pinus sylvestris* var. *iberica* Svoboda tras tratamientos térmicos

Publicación derivada de éste capítulo:

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Effect of seed mass and number of cotyledons on seed germination after heat treatment in *Pinus sylvestris* L. var. *iberica* Svob.

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Running title: Effect of seed mass and number of cotyledons after heat treatment on germination in *Pinus sylvestris*

Introduction

Pinus sylvestris L. (Scots pine) is the most representative pine tree in the mountain areas of entire Europe and one of the most widely distributed in the Iberian Peninsula, where it covers an area of 1,280,000 ha, of which 47% is natural forest and the rest is planted stands (Montero *et al.*, 2001a). It plays a key role in Spanish forestry due to its economic, ecological and social importance (Cañellas *et al.*, 2000; Palahí *et al.*, 2002). Scots pine forests reach their south-westernmost geographical limit in the high Mediterranean mountains of the Iberian Peninsula where *Pinus sylvestris* has diversified into several geographically-structured microtaxa, among which *P. sylvestris* var. *iberica* (Iberian Scots pine hereafter) occupies the high central mountains (Amaral Franco, 1986; Peinado and Rivas-Martínez, 1987).

Spanish mountains, included Scots pine forests, are affected by repeated and frequently human-induced fires (Martínez *et al.*, 2009, Montero *et al.*, 2001b). Due

to its sensitivity to high temperatures, it has been characterized as a rarely pyrophytic species (Reyes and Casal, 1995; Núñez and Calvo, 2000). Unlike certain Mediterranean pines such as *P. halepensis* Mill. and *P. pinaster* Aiton (Mirov, 1967), *P. sylvestris* does not have serotinous cones which open after a fire (Tapias *et al.*, 2004) therefore implying a lower resistance to the high temperatures reached in fires. However, fire prepares an appropriate seedbed by changing the soil characteristics, and eliminates herbaceous plant competitors (Hille and den Ouden, 2004) which explain the increasing seedling density of Iberian Scots pine after fires (Castoldi *et al.*, 2013).

Seed mass is a maternal plant effect and –as with other seed characteristics– it influences seed dispersal and germination (Roach and Wulff, 1987; Castro, 1999). Specifically, seed mass has a positive influence on early seedling growth in Scots pine (Wennström *et al.*, 2002). The number of cotyledons is also related to a maternal effect due to their relation with seed mass (Squillace, 1964). In Scots pine, the higher the number of cotyledons, the greater the growth height (Reich *et al.*, 1994). The number of cotyledons has been positively related to seed size and hence to early plant survival in pine species (Buchholz, 1946; Isik, 1985) other than Scots pine, of which the same behaviour could be expected. Southern European populations of Scots pine have heavier seeds than central and northern populations (Reich *et al.*, 1994). It is therefore important to know whether these maternal factors (seed mass and number of cotyledons) are an advantage against fire in southern European populations where fire is one of the key stressors. The interaction between

seed size-number of cotyledons and germination in a range of thermal-shock temperatures simulating fires in Scots pine is unknown.

Our working hypothesis is that seed size and number of cotyledons influence the germination of seeds after being subjected to temperatures simulating fire conditions. The specific objectives address the following questions: a) how does the combined effect of seed mass and heat influence germination? and b) how does the combined effect of number of cotyledons and heat influence germination?

Material and Methods

Seed source

Scots pine cones were collected in the Biological Field Station of the Complutense University located in the foothills of Guadarrama Mountains (Madrid region, 1,200 m a.s.l., 40°54'N, 3°52'W). In November 2011 we selected at least 10 cones each –before opening– from 10 dominant, healthy wild trees of similar size, obtaining 158 cones as a result from which 3,600 seeds were selected.

The area is flat with a negligible difference in altitude. The plant landscape is mainly a semi-natural forest consisting of patches of young *Quercus pyrenaica* Willd. mixed with stands of Iberian Scots pine (Castoldi and Molina, 2012). *Pinus sylvestris* trees reach an average height of 22 m and an average diameter at breast height of 48 cm. Open woodlands of *Fraxinus angustifolia* Vahl and subhumid meadows of *Agrostis castellana* Boiss. & Reuter occur in wetter soils. The area has undergone numerous burns as the consequence of prescribed slash-pile fire

management (1,708 slash-pile burns carried out in the last ten years, A. Canencia). The climate in the study area is sub-Mediterranean, with 895 mm of mean annual precipitation and a mean annual temperature of 10.1ºC (Elias Castillo and Ruiz Beltrán, 1977). Soils correspond to brown soils on silicate rocks (Guerra *et al.*, 1966). Soils are developed mainly on glandular gneisses and the average of pH soils in the area is 7.5 (Castoldi, unpublished data).

Experimental design

The seeds were previously removed from the cones by placing in a dry air oven at 45°C for 24 hours. We extracted the seeds from the cones manually and removed the seed wings. We used fresh seeds (taken directly from the cone and not from the ground) collected 23 days before the experiment without any prior selection in order to reproduce natural forest conditions. All the seeds were individually weighed with a precision balance and assigned to one of two seed mass classes (class I and class II, Table 1) defined for the bimodal distribution found in the data. Seed mass distribution was normal for each class (class I: 1.6-12.5 mg, mean and SD: 8.9±0.1; class II: 12.6-145.0 mg, mean and SD: 15±0.3). Since the correlation between seed weight and seed-coat weight in pines is highly significant (Yeatman, 1966) we considered only seed weight in our experiment. Combinations of four different temperatures (100°, 125°, 150° and 175°C) and two exposure times (1 and 5 minutes) were studied together with a control (no treatment). Treatments were the following: 1) 100°C, 1min, I class; 2) 100°C, 1 min, II class; 3) 100 °C, 5 min, I class; 4) 100°C, 5 min, II class; 5) 125°C, 1 min, I class; 6) 125°C, 1 min, II class; 7)

125°C, 5 min, I class; 8) 125°C, 5 min, II class; 9) 150°C, 1 min, I class; 10) 150°C, 1 min, II class; 11) 150°C, 5 min, I class; 12) 150°C, 5 min, II class; 13) 175°C, 1 min, I class; 14) 175°C, 1 min, II class; 15) 175°C, 5 min, I class; 16) 175°C, 5 min, II class; 17) control, I class; 18) control, II class. These temperatures were chosen because they are commonly used in Scots pine germination studies to reproduce natural fire conditions (Habrouk *et al.*, 1999; Escudero *et al.*, 1997; Núñez and Calvo, 2000). Four replicates of 50 seeds each were used for each treatment and placed on Petri dishes.

Seeds were placed on filter papers moistened with purified water. Germination was run at a constant temperature of 20°C and 28% HR (air) and 22ºC and 56% HR (germination tables) under constant illumination of 20 μE m-2s-1 (fluorescent lamp F 40 W/33 RS cool white light). Germination was checked daily at the same hour for 14 days. This period is considered sufficient since it has been reported that 98% of Scots pine seeds germinate in the first five days under constant light and temperature -20°C- (Nygren 1987). Come's criterion (1970) was followed to determine the germinated seeds: we considered that a seed had germinated when its radicle could clearly be observed outside the tegument, and its size was equal to the size of the seed. Seeds that were considered germinated were removed and the number of cotyledons counted in order to study the relation between it and seed size (length and width). After the experiment we investigated the un-germinated seeds by the cutting test and divided them into filled or empty seeds in order to study seed viability. Secondary fungi contamination was checked by recording the percentage

of fungi cover in the Petri dishes the 4^{th}, 8^{th} and the 14^{th} day and allocated to seven classes (Table 1). Fungi were taxonomically determined up to the genus level (Seifert *et al.*, 2011). All germination tests and seed weightings were performed in the Seed Laboratory at the Swedish University of Agricultural Sciences, Department of Southern Swedish Forest Research Centre, Alnarp (Sweden).

Table 1 Classes established to rank the fungal colonization in each Petri dish

Nb of infected seeds	Fungi cover (%)	Class
0	0	1
1	2	2
2-5	3-10	3
6-12	11-25	4
13-25	26-50	5
26-37	51-75	6
38-50	76-100	7

Statistical analysis

Germination capacity (GC) and mean germination time (MGT) were calculated for each treatment as follows: GC (%) = (Nº germinated seeds/total Nº of seeds sown)*100; MGT (days) = Σ (n_i * i)/N, where n_i is the number of seed germinated on day i and N is the total number of seeds germinated along the study period (Bewley and Black, 1994).

Data were checked for normality or transformed if necessary, and ANOVA was performed to test the effects of heat and seed mass on germination (both GC and

MGT). A Student's t-test was applied to identify statistically significant differences in GC and MGT between the control and the treated seeds. One-way ANOVA was performed to determine significant differences between heated and control seeds, among heat treatments, between seed mass classes and between heated and control seeds in fungi second contamination. Three-way ANOVA was used to consider the temperatures (H), exposure times (T) and seed mass (S) together. Spearman's coefficient was used to relate the GC and MGT variables and number of cotyledons and seed size (length and width used as independently variables). A generalized regression model (GRM) with stepwise procedure was performed to investigate the interactions between seed mass and temperature and exposure time. Spearman's rank correlation coefficient and linear regression analysis were used to relate seed size to number of cotyledons. Student's t-test was used to compare the number of cotyledons in seedlings after heat treatment and in control. Statistical analyses were done using SPSS 13.0 and STATISTICA software.

Results

Over the total sowed seeds the 15% germinated. On cutting the un-germinated seeds, we found the 85.8 % were full. Thus the majority of the seed material was healthy and failed to germinate due to the treatments. Treated seeds showed the highest GC at 100ºC for 1 min (53%), and decreased with higher temperatures and longer exposure times (H-100 T-5; H-125 T-1) (Fig. 1). GC was depressed at above 125°C for 5 min. There were significant differences in GC between treatments and controls and among the treatments (in both cases $p<0.001$).

GC was negatively influenced by temperature ($F_{2,23}$=12.61, p<0.001) and exposure time ($F_{2,23}$=26.91, p<0.001). The less aggressive heat treatment (100ºC, 1 min) already shows significant differences in GC in comparison to the control ($F_{1,22}$=17.31, p<0.001).

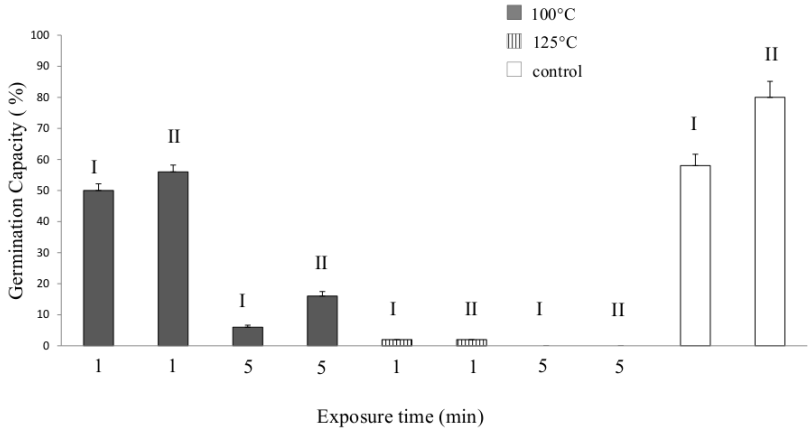

Fig. 1 GC of Iberian Scots pine seeds in response to heat treatments and control. Labels correspond to seed mass classes (I and II class) and exposure minutes (1 or 5 minutes). Values are mean ± SD. Differences between treatments and control are significant for all treatments, except for the first one (100°C, 1 min, I seed mass class, first column; p=0.199). Heat treatments that avoid germination capacity are not shown with the exception of the treatment 125ºC, 5 min.

The seed mass had a significant effect on GC when considering heat treatment at 100°C for 5 minutes ($F_{1,6}$=9.375, p=0.02) and the control ($F_{1,6}$=23.45, p=0.003). In contrast, seed mass had no significant effect on GC when considering heat treatment at 100°C for 1 minute ($F_{1,6}$=1.652, p=0.246), or when all the treatments were considered together ($F_{1,24}$=1.14, p=0.29).

The first seedlings were observed in the control 4 days after sowing, with the highest seedling counts seen after 5 days. Table 2 shows that the lowest MGT was observed in the control, with no exposure to heat. MGT was influenced by temperature ($F_{2,23}$=27.59, p<0.001) and exposure time ($F_{2,23}$ = 54.79, p<0.001).

Table 2 Mean germination time (days) of seeds of Iberian Scots pine in response to different exposure time to dry heat at different temperatures and times (Mean ± SD).

Time	Seed Mass	100ºC	125ºC	150ºC	175ºC
1 min	I	8.84 ± 2.7	14 ± 0	0	0
	II	9.59 ± 2.1	14 ± 0	0	0
5 min	I	13.60 ± 0.9	0	0	0
	II	13.20 ± 1	0	0	0
		No treatment			
Control	I	5.83 ± 2.7			
	II	5.89 ± 4.6			

MGT differences between all heat treatments and the control were not supported statistically ($F_{1,70}$=1.82, p=0.181) but they were when considering the less aggressive heat treatments of 100ºC for 1 min ($F_{1,14}$=74.12, p<0.001) and 100ºC for 5 min ($F_{1,14}$=993.08, p<0.001). The difference in MGT between the heat treatment of 125ºC for 1 min and the control was not significant ($F_{1,14}$=1.06, p=0.321). MGT varied among the different heat treatments (p<0.001). The seed mass had no significant effect on MGT ($F_{1,24}$=0.008, p=0.93). Generalized Regression Model showed that there are not significant interactions between seed mass, temperature and exposure time in MGT (Table 3). The stepwise procedure kept the two first variables in the model (T and H). The germination capacity (GC) and mean

germination time (MGT) were negatively correlated, meaning that lower MGT corresponds to a high GC (r=-0.9143, p<0.001, Fig. 2).

Table 3 Generalized Regression Model. H: temperature, T: exposure times and S: seed mass.

Summary of stepwise regression; variable: MGT (Spreadsheet1) Forward stepwise P to enter: .05, P to remove: .05							
	Steps	Degr. of freedom	F to remove	P to remove	F to enter	P to enter	Effect status
T	Step Number 3	2	60.25485	0.000000			In
H		2	35.07437	0.000000			In
S		1			0.17895	0.676795	Out
T*S		2			1.10146	0.352695	Out
H*S		2			0.08896	0.915258	Out

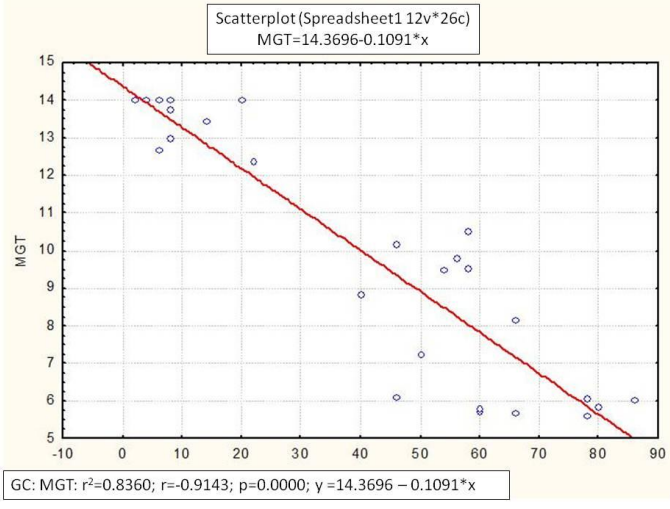

Fig. 2 Spearman's correlation between the dependent variables Germination Capacity (GC) and Mean Germination Time (MGT)

Descriptive statistics of cotyledons number, seed width and length for treated and control seeds are shown in Table 4. The number of cotyledons in 14-day-old seedlings was positively correlated to seed size ($r=0.358$, $p<0.001$). The number of cotyledons was positively correlated to seed length ($r=0.1203$, $p=0.005$) and to seed width ($r=0.0949$, $p=0.002$). This result was confirmed by a linear regression analysis between seed size and the number of cotyledons that was highly significant ($F=13.927$, $\beta=0.358$, $p<0.001$). The number of cotyledons in seedlings after heat treatment did not differ significantly from the number of cotyledons in the control seeds ($p=0.1034$). (t-test heat treatment mean =6.7, control mean 7.1, $p=0.1069$).

Fungal colonies of cosmopolitan and ubiquitous fungi taxa such as *Trichoderma* sp., *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Alternaria* sp., and *Mucor* sp. were found infecting the Petri dishes. The highest percentages of fungi cover (25% or more seeds infected) were recorded in seeds submitted to temperatures above 125ºC. There was no significant difference in fungi cover between heated and control seeds for each measuring day (day 4^{th}: $F_{1,70}=0.679$, $p=0.413$; day 8^{th}: $F_{1,70}=1.22$, $p=0.272$; day 14^{th}: $F_{1,70}=2.13$, $p=0.149$).

Table 4 Descriptive statistics of seed traits (seed mass class, number of cotyledons, width and length of seed) for heated (all treatments) and control seeds.

		mean	min	max	SD
Heated seeds					
Seed mass class I (N=40)	N° cotyledons	6.675	5	9	0.79703
	Width (mm)	53.15	44	61	3.886532
	Length (mm)	27.775	23	35	3.166228
Seed mass class II (N=40)	N° cotyledons	6.8	5	8	0.790975
	Width (mm)	56.175	50	64	3.685644
	Length (mm)	29.05	22	33	2.406721
Control seeds					
Seed mass class I (N=10)	N° cotyledons	7.3	6	8	0.674949
	Width (mm)	55.1	48	62	4.629615
	Length (mm)	55.1	25	30	1.523884
Seed mass class II (N=10)	N° cotyledons	7	6	8	0.666667
	Width (mm)	58.1	53	62	3.142893
	Length (mm)	28.4	25	31	1.712698

Discussion

As expected from the background literature our results showed that germination is depressed by temperature and long exposure. A temperature range between 120ºC and 150ºC has been reported in failed GC of Scots pine seeds from Spain (Habrouk *et al.*, 1999; Escudero *et al.*, 1997; Núñez and Calvo, 2000). Our results showed that heat treatments at 125°C for 5 min on healthy Iberian Scots pine seeds resulted in null germination. Moreover, long exposure (5 min) notably decreases GC even at the lowest temperature studied in this work (100ºC). The slight differences seen by authors in the temperature threshold for germination can be explained by experimental conditions such as light time exposure or the seed provenance. Significant delays have been reported in germination time after heat treatments (Escudero *et al.*, 1997) increasing the MGT both temperature and exposure time (Habrouk *et al.*, 1999) Our results support this pattern and show that temperature and exposure time affect MGT even at the lowest temperature shock of 100ºC in our experiment.

Previous studies on the influence of seed mass on germination in different pine species show contradictory results. Some report a positive correlation (Simak and Gustafsson, 1954; Debain *et al.*, 2003; Tíscas and Lucas, 2010), whereas other studies show no effect (Mikola, 1985; Zaborovskii, 1966; Parker *et al.*, 2006; Bladé and Vallejo, 2008). In Spanish Scots pines, seed mass has been positively correlated with germination (Castro, 1999). This agrees with our results on Iberian Scots pine showing that seed mass is positively related to germination when seeds are unheated.

Furthermore, seed mass still positively influences GC in moderately heated seeds, which still retain the ability to germinate. Seed mass is also positively related to the number of cotyledons (Reich *et al.,* 1994) as our results also support. Thus it could be inferred that seeds with a higher number of cotyledons should have a better performance when germinating under moderate heat. However, due to the nature of the data this cannot be probed.

Southern European populations of Scots pine are known to have heavier seed mass (Reich *et al.*, 1994) –as our results confirm– and a higher number of cotyledons in relation to central and northern Scots pines. Since fire is one of the most important perturbations under the Mediterranean climate, the seed mass besides the number of cotyledons could confer a maternal advantage against this stressor in low-intensity fires.

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IV.

Primeras etapas en la sucesión vegetal tras quemas controladas en un bosque manejado sub-Mediterráneo

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REGULAR PAPER

Early post-fire plant succession in slash-pile prescribed burns of a sub-Mediterranean managed forest

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Background and aims – This is the first report on early vegetation dynamics in prescribed slash-pile burns under a sub-Mediterranean climate. We studied a managed forest system of *Pinus sylvestris* plantations in the upper belt of *Quercus pyrenaica* forests in the Guadarrama Mountains (Spanish Central System). We investigated post-fire plant succession in order to assess how fire affects tree regeneration and species composition (vascular plants, bryophytes and fungi) in the first three years.
Methods – Species composition, species cover, number of pine seedlings and ecological data were recorded in twenty slash-pile burnt plots and twenty control plots the first and second year after fire. To identify ecological indicators and examine post-fire succession, we determined Indicator Analysis and Neighbour Joining Tree, respectively. Wilcoxon's signed-ranks test and Spearman's coefficient of rank correlation were used to study the effects of fire on pine seedlings survival and its changes overtime. Principal Components Analysis was performed to assess the relationships between environmental and structural variables in burnt plots.
Key results – The early plant community established after slash-pile prescribed burns was characterized by three pioneer species: *Funaria hygrometrica* (moss), *Coltricia perennis* and *Psathyrella pennata* (fungi). No taxonomical changes were detected in vascular plant families but there was an increased presence of therophytes and pine seedlings. Two early vegetation stages were identified relating to species richness and *Funaria hygrometrica* cover. Fire significantly increased pine seedlings density, which subsequently decreased overtime. Survival of one-year old pine seedlings was unrelated to the year of the burn.
Conclusions – We highlight the importance of bryophyte and fungi species in comparison to seeder species as indicators of recent prescribed slash-pile burns under a sub-Mediterranean climate; and also point out the impact of prescribed slash-pile burns on pine seedling recruitment after the first years post-fire. This recruitment decelerates over time in burnt sites, and it is more pronounced in control plots.

Key words – Anthropic fire, Iberian Peninsula, permanent plots, *Pinus sylvestris*, post-fire succession, *Quercus pyrenaica*.

INTRODUCTION

Anthropogenic disturbance on Earth is substantial and growing (Niemelä et al. 2000, Zalasiewicz et al. 2011). Human activities such as farming, forestry, land-use change and urbanization create patchworks of modified landscape affecting the vegetation in many different ways and at various levels (Wardle et al. 2011). Among human activities, fire is a major disturbance factor in many of the world's ecosystems, particularly in regions under a Mediterranean climate with seasonally dry conditions (Ojeda et al. 1996). One of the common forest management systems in Mediterranean countries is doing slash-pile prescribed burns (Pérez & Moreno 1998), which consists of cutting and burning tree branches, in small circular stands, in order to reduce fire risk, increase establishment of understory vegetation, control tree and shrub growth and to eliminate branches affected by insect pests (Haskins & Gehring 2004). This management is much extended in Spanish Central System. The piles are composed by branches of the most common trees or shrubs in the area such as *Quercus pyrenaica* Willd., *Pinus sylvestris* L. and in less extent *Fraxinus angustifolia* Vahl. and *Prunus spinosa* L. Plots of one to two square metres are burnt each spring at different sites before the dry season. The Peñalara Nature

Reserve where the study area is located provides appropriate legislation for conducting prescribed burns when necessary, after obtaining the permits. As an example, in our 50-ha study area, 1708 slash-pile burns were carried out in the last ten years, representing 0.6% of the total area, with a large number of marks remaining from old burns.

Fire is a disturbance which provides a good opportunity to study plant succession (Rice 1993, Mutch & Parsons 1998). The investigation of the factors that affect plant succession is critical to an understanding of future fire regimes in managed areas (Pérez & Moreno 1998). Moreover, vegetation dynamics in the early stages after fire can determine the structure and composition of the community in the future (Keeley & Keeley 1981, Valbuena et al. 2000). In extensive wildfires, above-ground vegetation structures in the understorey are usually killed and the risk of wildfire is closely related to land cover (Bajocco & Ricotta 2008). Since the high fuel loads and long duration of intense heat, slash-pile burns produces alterations to abiotic and biotic site conditions (Creech et al. 2012). However, there is little information on vegetation responses to focalized fires such as those created by slash-pile burns in Mediterranean area, which are characterized by high-intensity.

Sub-Mediterranean forests in Spanish siliceous mountains frequently consist of deciduous sub-Atlantic Pyrenean oak forests (*Quercus pyrenaica*) and evergreen sub-Mediterranean Scots pine forests (*Pinus sylvestris*) distributed along an altitudinal gradient. The change from one forest type to the other occurs from 1200 to 1400 m a.s.l. according to certain authors and is a controversial topic (Cañellas et al. 2000). Oak woods of *Quercus pyrenaica* are listed in the Habitat Directive (92/43/EEC), as a natural habitat type of European community interest for conservation (habitat code 9230). Regional representation of these forests consists of mostly young oak formations dedicated to pastures or mixed stands of planted Scots pines. *Pinus sylvestris* has been widely planted in the sub-Mediterranean areas in Spanish siliceous mountains due to its value for timber production, particularly in the upper altitudinal belt of the *Quercus pyrenaica* distribution. This management system is usually accompanied by slash-pile prescribed burns. Thus, these semi-natural forested areas offer a good scenario to study both the vegetation succession after prescribed burns and also the different early response to fire by the gymnosperm dominant tree species. Our hypotheses are that slash-pile prescribed burns influence vegetation dynamics and that in this management the obligate seeders are favoured (Abrahamson 1980). The main objective of this work is to investigate the relationships between past and current management regimes in the territory, where vegetation response is crucial to understanding the current plant landscape and the main environmental driving factors. This work aims to investigate early post-fire succession focusing on vascular plants, bryophytes and fungi, and on forest regeneration through tree recruitment.

METHODS

The study area is located in Peñalara Natural Park (Rascafría, 1200 m a.s.l., 40°54'N 3°52'W, Madrid, central Spain). It corresponds to a semi-natural forest ecosystem of 50 ha in the foothills of the Sierra de Guadarrama (Spanish Central System), mainly consisting of patches of young *Quercus pyrenaica* mixed with stands of *Pinus sylvestris*. The area presents numerous burns as the consequence of slash-pile fires every year over the past decades. The area has a sub-Mediterranean climate with a summer drought period (Fernández-González 1991). Mean annual precipitation (P) is 1030 mm, and mean annual temperature (T) is 9.8ºC. Mean summer precipitation is 91 mm and mean summer temperature is 17.5ºC. Mean winter precipitation is 324 mm and mean winter temperature is 3.3ºC. In the study area, *Pinus sylvestris* trees reach an average height of 22 m and a dbh of 130 cm, whereas *Quercus pyrenaica* trees reach an average height of 7 m and a dbh of 23 cm (Castoldi & Molina 2012). Soils in the study area correspond to brown soils on silicate rocks (Guerra et al. 1966).

The following references were used for the nomenclature of species: Castroviejo et al. (1986–2002) and Tutin et al. (1964–1980) for tracheophytes; Casas et al. (2001) for moss; Bon (1988) for fungi; and Pignatti (1982) for Raunkiaer's life-forms.

Floristic composition and species cover were recorded in forty randomly located one-square-meter plots (fig. 1). In order to study plant succession in the first and second year after fire, twenty burnt plots (ten burnt in spring 2008 and ten burnt in spring 2009) were sampled and the percent cover was assigned for each species found in June 2010 and 2011, the most phenologically favourable period. With regard to the real time elapsed since the last fire, plots burned in 2008 were sampled two and three years after the burn, and plots burned in 2009 were sampled one and two year after. Twenty non-burnt plots close to the burnt ones were taken as a control and sampled to interpret the impact of the fire on the initial conditions. We recorded some environmental variables related to forest structure such as canopy cover, closest pine tree diameter at breast height (dbh), number of pine trees in a 15 m radius, distance from principal pine tree, number of pine cones and oak litter cover. In burnt plots we also recorded the burnt remains of plant matter, namely here charcoal, as a surrogate of fuel amount and burning duration. Species richness was determined as the number of species per plot. *Pinus* seedlings were counted in 2010 in order to monitor their survival in the first three years after the fire.

Indicator species analysis (Dufrêne & Legendre 1997) was used to identify species as ecological indicators of environmental changes; in this case to calculate plant species fidelity to burnt locations (PC-ORD 4 software, McCune & Mefford 1999.). Neighbour joining tree was determined on the squared Euclidean distance computed between the quadrats to examine floristic post-fire succession (Syntax 2000 software, Podani 2001). Squared Euclidean Distance is a dissimilarity index strongly sensitive to dominant species (van Tongeren 1995). A completely empty quadrat corresponding to the precolonization stage (i.e. no plant cover) was used as outgroup to root the tree diagram. The sample plots were investigated synchronically in 2010 in order to study the presence of taxa in twenty burnt plots for two consecutive years (2008, 2009) and in twenty unburnt plots, thus yielding a total of forty objects. Additive trees have been successfully used to investigate post-fire successional processes in *Pinus*

Figure 1 – Examples of the slash-pile prescribed burns studied in mixed *Quercus pyrenaica* patches and *Pinus sylvestris* stands of Central Spain: A, canopy layer; B, recently burnt; C, burnt and control plot samples; D, grid used in sampling plots.

plantations (Podani et al. 2000). Wilcoxon's signed-ranks test and Spearman's coefficient of rank correlation were used to estimate the effects of fire on pine seedlings survival and their changes during the first three years after fire (SAS 9.2, SAS Institute Inc. 2008). Since our design consisted of paired plots (one burnt plot and one control plot) we performed our statistical analyses taking into account samples nested in site (ten sites per year). Environmental and structural affinities of burnt plots were assessed by proximity in a multivariate space defined by components extracted from a principal components analysis (species-centred PCA, CANOCO software, ter Braak & Šmilauer 2002).

RESULTS

Species indicators

Sixty-seven taxa were identified in the plots. Forty-one species occurred in both burnt and unburnt situations. Fifteen species were exclusively found in burnt plots and eleven in control plots. Most of the species sampled in unburnt plots correspond to herbaceous perennial plants, including characteristic species of meadows (*Arrhenatherum elatius* subsp. *bulbosum* and *Ranunculus bulbosus* subsp. *aleae*), grasslands (*Jasione montana* and *Luzula campestris*), wood fringes (*Filipendula vulgaris*) and understorey deciduous forests of Querco-Fagetea (*Hedera helix* and *Stachys officinalis*). It was also worth noting the occurrence of certain nanophanerophytes such as *Crataegus monogyna*, *Rosa canina* and *Rubus* sp. Fifteen species were found only in burnt sites, of which two are fungi (*Coltricia perennis* and *Psathyrella pennata*) and one is moss (*Funaria hygrometrica*). The rest correspond to vascular species characteristic of wood fringes (*Galium aparine* and *Vicia tenuifolia*), grasslands (e.g. *Senecio jacobaea*, *Trifolium repens* and *Trifolium campestre*), and weeds (*Veronica arvensis*). Indicator species analysis identified one bryophyte and two fungi as characteristic species of post-fire situations: *Funaria hygrometrica*, *Psathyrella pennata* and *Coltricia perennis* (table 1).

Table 1 – **Indicator species analysis results.**
Relative frequency (%) and Indicator values of the three pioneer species of post-fire slash-pile burnt and unbrunt plots conditions in a Submediterranean forest ecosystem. Values are referred to ten plots established in each treatment. Indicator values of taxa identified by indicator species analysis as being significant indicator species are shown in the last column. * $p < 0.05$; *** $p < 0.001$.

Species	Burn plots		Unburnt plots	Indicator Values
	2008	2009		
Coltricia perennis	27	78***	-	58.2***
Funaria hygrometrica	91***	78	-	49.0***
Psathyrella pennata	36*	11	-	28.7*

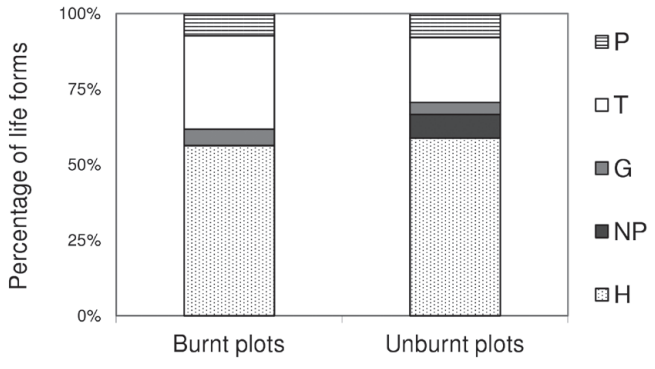

Figure 2 – Raunkiaer's life-forms spectra in burnt and control plots. H, Hemicryptophytes; NP, Nanophanerophytes; G, Geophytes; T, Therophytes; P, Phanerophytes.

Mean species richness is higher in control sites (11 ± 2.8 SD) than in burnt sites (8 ± 3.3 SD). No taxonomic changes were found between burnt and control plots for the best represented families of vascular species, namely Fabaceae and Poaceae in both cases. However, a marked decrease in species was found for Rosaceae in burnt plots (electronic appendix). The results also showed that burnt sites included a higher proportion of therophytes and lack of nanophanerophytes in comparison with unburnt sites (fig. 2). Nevertheless, hemicryptophytes were the dominant growth forms in both situations.

Post-fire succession

Our results show that in the first year after fire, mean (± SD) species richness is 6.9 ± 2.3 and in the second year increases to 8.8 ± 2.8. Neighbour joining tree shows a close-to-origin cluster corresponding to a first stage post-fire condition, mainly including first-year post-fire plots with lower species richness and a lower occurrence of the moss *Funaria hygrometrica* (fig. 3). A second stage post-fire condition (Group A) can be distinguished by both first- and second-year post-fire plots with intermediate species richness and the constant presence of *Funaria hygrometrica*. This group A is close to the cluster containing most control plots (Group B) which in its turn has the higher species richness (*t*-test mean A = 8.8, mean B = 6.9, p = 0.0125). Electronic appendix shows frequency and mean absolute cover of the 65 most frequent species in burnt and control plots.

Fire significantly increases pine seedlings density ($p < 0.0001$, table 2). A significant positive correlation was noted between the closest pine tree dbh and the number of cones in burnt plots (Spearman's rho = 0.73, $p < 0.05$). Additionally, a significant decrease was also observed in pine seedling density over time ($p < 0.0001$, table 2), and this reduction was greater in control plots than in burnt situations ($p < 0.005$, table 2). PCA shows that the year of the burnt is unrelated to the one-year survival percentage of pine seedlings. The year of the burnt it is positively related to soil charcoal content and negatively related to oak litter. Pine seedling density is positively related to oak litter and negatively to charcoal (fig. 4).

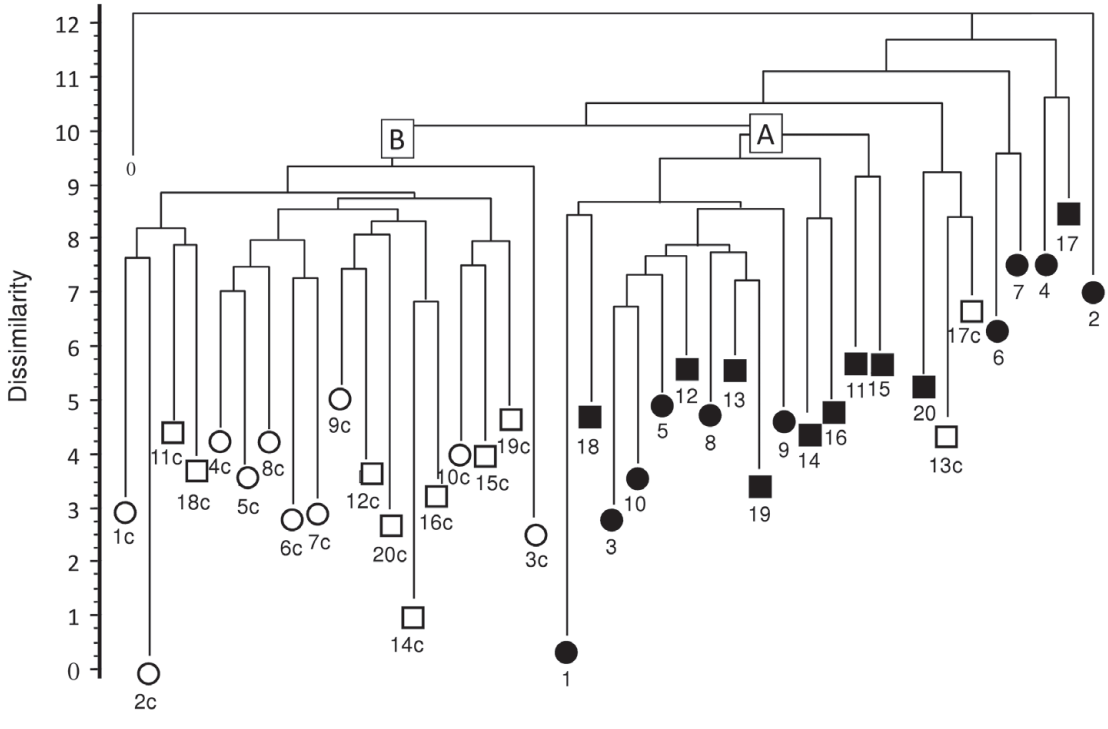

Figure 3 – Neighbour joining tree for the post-fire succession data. Sites consist of twenty burnt and twenty unburnt (control) plots, the latter follow by C. Dark circles represent plots sampled 2 years post-fire, and dark squares are plots sampled 1 year post-fire. Empty symbols are control plots. 0 is the outgroup without vegetation used to root the tree.

Table 2 – **Comparison between burnt and unburnt sites**.
The plots were compared taking into account pine seedlings, pine cones, oak cover litter and pine seedling establishment over time. Plots were sampled in 2010 (10) and 2011 (11). * $p < 0.005$; ** $p < 0.0001$.

	N	Mean	Standard deviation	Minimum	Median	Maximum
Burnt plots						
Pine seedlings 10	20	149.40	67.50	60.00	124.00	298.00
Pine cones 10	20	7.20	12.19	0.00	2.00	48.00
Oak litter cover 10	20	4.90	2.17	2.00	5.00	9.00
Pine seedlings 11	20	93.10	49.11	33.00	81.00	201.00
percentage change of pine seedlings 10-11	20	-35.90**	22.15	-65.83	-36.72	0.00
Unburnt plots						
Pine seedlings 10	20	38.05	33.93	0.00	31.00	149.00
Pine cones 10	20	17.50	31.22	0.00	1.00	118.00
Oak litter cover 10	20	7.00	2.55	0.00	8.00	9.00
Pine seedlings 11	20	14.70	17.24	0.00	10.00	67.00
percentage change of pine seedlings 10-11	19	-64.63*	31.73	-100.0	-73.24	25.00
Comparison of the percentage change of pine seedlings 10-11 between unburnt and burnt plots	19	27.72	30.81	-43.10	34.81	82.03

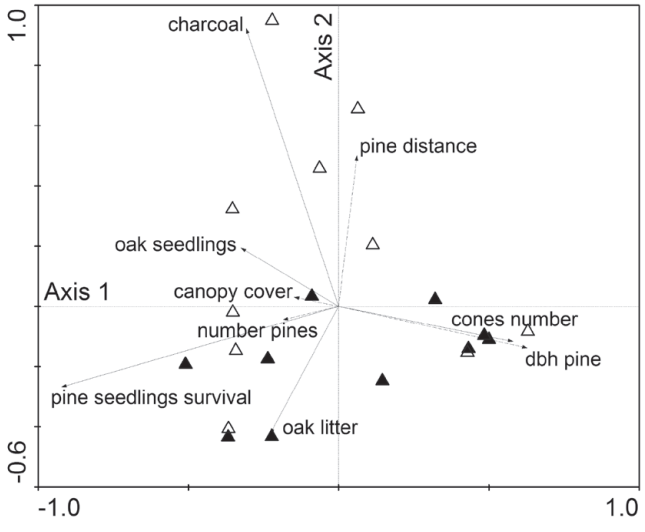

Figure 4 – Principal Components Analysis (PCA) plot of the variables studied. First and second principal components (PC1 and PC2) explain 47.1% and 24.3% of the total variance respectively. Vector variables abbreviations correspond as follows: charcoal (burnt remains of plant matter), cones number (number of pine cones), dbh pine (dbh of the nearest pine), distance pine (distance from principal pine tree), number pines (number of pine trees in a 15 m radius), pine seedlings survival (one-year survival percentage of pine seedlings), oak litter (oak litter cover). Empty triangles represent plots burnt in 2008, and dark triangles are plots burnt in 2009. Structural variables are represented with a continuous line and environmental variables with dashed line in the biplot.

DISCUSSION

Our results point out the importance of spore species in comparison to seeder species as indicators of recent slash-pile prescribed burns under a sub-Mediterranean climate. The three taxa revealed here as characteristic species, *Funaria hygrometrica*, *Psathyrella pennata* and *Coltricia perennis*, are known as colonizers of post-fire soils under different extra-tropical climates (Visser 1995, Baar 1996). In post-fire situations, mosses can act as the first colonizers, soon forming a dense layer which locally favours the establishment of new species (Bradbury 2006). Specifically, the moss *Funaria hygrometrica* is related to temporally unstable sites, particularly charred surfaces (Delasheras et al. 1994, Esposito et al. 2009), and prepares the ground for a subsequent colonization of vascular plants, as well as counteracting erosion in the early post-fire stages. However post-fire vascular species content closely resembles the initial floristic composition (Purdie & Slatyer 1976) which in the case of our study mainly consists of plants from the surrounding vegetation such as grasslands and wood fringes.

Germination response after fire is not randomly distributed across life-forms, and the type of germination behaviour is related to certain growth forms (Keeley & Bond 1997). In post-fire conditions, annual species are predominantly triggered by chemicals from smoke and/or charred wood (Keeley et al. 2005). This fact explains why therophytes can be an important component in the early stages of post-fire succession, playing an important role in preventing loss of nutrients from the soil (Kazanis & Arianoutsou 1996, Pérez &

Moreno 1998, Guo 2001). However, fire relatively influences the diversity patterns of growth forms (Lloret & Vilà 2003). Our results show that although therophytes are favoured after prescribed burns, hemicryptophytes remain dominant; these are also the dominant growth forms in the surrounding plant landscape.

The results found for changes in species richness after fire over time vary according to different authors. Some report an increase in substrate stability and species richness as a result of the gradual development of the vascular plant cover (Foster 1985, Podani et al. 2000). Others indicate a decrease after fire, which can be attributed to the increased cover of matrix species resulting from enhanced productivity (De Grandpré et al. 1993). It is worth noting that the diversity peak in the immediate post-fire year (or two) appears to be driven by factors different from those in subsequent diversity peaks (Keeley et al. 2005). In slash-pile prescribed burns, we found two plant-succession steps throughout the two first years post-fire. They are characterized by an increase in species richness, and specifically an increase in the cover of two characteristic species, *Funaria hygrometrica* and *Coltricia perennis*. Further investigations into these patterns are required in order to determine how long these characteristic species remain.

The contrasting growth of *Pinus sylvestris* and *Quercus pyrenaica* seedlings can be explained by the fact that cone pines have orthodox seeds which can survive after a desiccation period, while acorns have recalcitrant seeds (Pammentera & Berjaka 1999). High germination of pines after fire has also been attributed to the opening of pinecones and the preparation of an appropriate seedbed (Trabaud 1987, Núñez & Calvo 2000). Our results indicate the importance of slash-pile prescribed burns in pine seedling recruitment after the first years post-fire. However, the expectation of pine seedling establishment decelerates over time in burnt sites, although to a lesser extent than under the unburnt understory. The fact that the year of the burn it is positively related to soil charcoal content and negatively related to oak litter is probably fortuitous. The pine seedlings are positively related to oak litter and negatively to charcoal.

Thus, the current management of *Quercus pyrenaica* forests including plantations of *Pinus sylvestris* and slash-pile prescribed burns implies ecological niches where plant succession can be studied. A massive germination of sexual pine diaspores is followed by a later decline in pine seedling establishment over time. This declining it also occurs but is more pronounced in control plots.

SUPPLEMENTARY DATA

Supplementary data are available in pdf format at *Plant Ecology and Evolution*, Supplementary Data Site (http://www.ingentaconnect.com/content/botbel/plecevo/supp-data), and consist of a table with the frequency (Frq) and mean absolute cover (Mean) of the 65 most frequent species in burnt and control (unburnt) plots.

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Apéndice 2

Resultados preliminares sobre cambios edáficos tras quemas de residuos de corta en un ambiente forestal sub-Mediterráneo

Apéndice 2

Preliminary results on soil changes after slash-pile burning in a sub-Mediterranean forest environment

Resultados preliminares sobre cambios edáficos tras quemas de residuos de corta en un ambiente forestal sub-Mediterráneo

Introduction

Fire affects vegetation and soil in several ways. It may consume part or all of the sanding plant material and litter, as well as the organic matter in the upper layers of soil (De Bano and Conrad 1978). Nutrients are either made more available or can be volatilized and lost from the site. Some of the soluble nutrients deposited in the ash may be lost from the site by erosion if not immediately absorbed by plants (De Bano and Conrad 1976). Chemical components as C, N and P are greater 1 y after a fire and declined in soils as time since the last fire increased (Dumontet et al. 1996). Prescribed fires in forest management, promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients (Certini 2005). A clear understanding of the mechanisms of disturbance effects on ecosystems is essential to interpret current ecosystem structure, to design effective strategies of forest management and restoration and to predict ecosystem responses to future changes in disturbance regime.

The aim of this study was to understand the effect of slash-pile prescribed burns in the first years after burn, in soil composition and changes through time in a Mediterranean forest. Thus, we have data about the first three years after burnt.

Material and Methods

Soil sampling and analysis

Soil was sampled in 30 burnt plots and in 10 control plots. In each plot, a surface soil sample (0–10 cm) was collected following the ISRIC methodology (Reeuwijk 2002). Regarding burnt plots 10 of them were burnt in 2008, 10 in 2009 and 10 in 2011. In the latter (2011), we collected recent ashes layer after burning in order to have initial ions composition and a wider temporal scale data. In only four burnt plots was possible to distinguish the ash layer. Data were recorded in 2010 (for plots burning in 2008 and 2009) and 2011 (for all plots). One soil cylinder of known volume was recorded in order to estimate moisture percentage gravimetrically.

Ionic composition of soluble salts in soils was analysed after an extraction in distilled water (soil water 1:5). Anions (Cl^- NH_4^+, SO_4^{2-}, NO_2^- ,NO_3^- and PO_4^-) and cations ($K^{+,}$ Na+, Ca^{2+} and Mg^{2+}) were performed in laboratory at room temperature using a Metrohm model 761 Compact IC (Metrohm, Herisau, Switzerland) and a Sherwood 410 flame photometer (Sherwood Scientific Ltd., Cambridge Science Park, Cambridge, England). Since fire induces transformations of organic N and changes its forms, we calculated the total N inorganic form concentration from ionic composition data of NH_4^+, NO_2^- and NO_3^- (Knicker et al. 1996). Soil Organic carbon was measured using wet combustion method, following Walkley-Black analysis by potassium dichromate oxidation and subsequent assessment. Electrical conductivity, pH and moisture analyses were determined following the ISRIC methodology (Reeuwijk 2002). Munsell Colour criterion (1975) was follow to establish colour samples. Two-way ANOVA was performed in order to compare soil characteristics between burnt and control plots and between burnt plots of different years, considering the plots as independent groups (Statistica software).

Results

Descriptive statistics of burnt plots in different years and control plots are shown in Table 1. ANOVA analysis showed that burnt and control plots are different in soil

composition and properties. Burnt plots showed a more alkaline soil, with less organic matter and characterized by an increase in Na^+, K^+, Ca^{2+}, Mg^{2+}, N, PO_4^- and SO_4^{2-}. Soil evolves through the first three years after fire, increasing moisture, decreasing ionic concentration and gradually approaching to the initial condition (represented in our study by the controls). There is significant difference between all the independent groups of burnt plots (burned in 2008, 2009 and 2011) and control plots (burnt in 2008: $F_{13,6}$=18.49, p=0.0009; 2009: $F_{13,6}$=24.89, p=0.0003; 2011: $F_{13,6}$=102.27, p=0.000006). Chemical and physical parameters change in burnt plots over years. There is significant difference among different times of the burnt (2008 and 2009: $F_{13,6}$=19.56, p=0.0007; 2008 and 2011: $F_{13,6}$=29.94, p=0.0002; 2009 and 2011: $F_{13,6}$=11.39, p=0.003).

Table 1: Descriptive statistics of burnt and control plots. Ashes correspond to recent ashes recorded in plots burnt in 2011.

	plots	N	min	max	media	st.dev.
EC (dS/m)	Ashes	4	0.001653	0.011961	0.004668	0.004910
	Burnt 2011	10	0.000321	0.007880	0.001658	0.002248
	Burnt 2009	10	0.000103	0.000336	0.000246	0.000070
	Burnt 2008	10	0.000105	0.000241	0.000180	0.000047
	Control	10	0.000061	0.000223	0.000096	0.000049
pH	Ashes	4	8.970	10.110	9.550	0.477
	Burnt 2011	10	7.300	9.450	8.174	0.860
	Burnt 2009	10	6.560	8.140	7.313	0.399
	Burnt 2008	10	6.300	7.440	7.018	0.352
	Control	10	5.460	6.280	5.803	0.241
Moist (%)	Ashes	4	0.000	0.000	0.000	0.000
	Burnt 2011	10	1.320	4.990	3.723	1.290
	Burnt 2009	10	2.122	5.865	3.537	1.161
	Burnt 2008	10	17.360	34.630	26.581	5.277
	Control	10	3.599	5.704	4.670	0.695
OM (%)	Ashes	4	6.603	23.359	11.569	4.808
	Burnt 2011	10	1.956	22.038	13.177	7.712
	Burnt 2009	10	3.841	14.568	8.636	4.123
	Burnt 2008	10	7.530	16.300	11.552	2.660
	Control	10	19.316	45.637	34.136	11.741
Na^+	Ashes	4	13.922	39.057	30.845	11.565

	Burnt 2011	10	17.810	121.871	47.477	38.253
	Burnt 2009	10	51.448	146.917	81.564	34.959
	Burnt 2008	10	14.443	28.288	20.927	4.529
	Control	10	7.268	19.795	12.803	3.445
K^+	Ashes	4	0.000	0.000	0.000	0.000
	Burnt 2011	10	0.000	480.175	135.002	197.204
	Burnt 2009	10	3.236	165.608	23.982	50.017
	Burnt 2008	10	13.689	129.052	74.424	41.539
	Control	10	11.883	26.382	15.964	4.696
Ca^{2+}	Ashes	4	28.270	121.609	66.691	45.945
	Burnt 2011	10	148.457	640.734	340.726	142.608
	Burnt 2009	10	80.652	428.682	261.589	96.855
	Burnt 2008	10	59.152	401.100	157.107	103.854
	Control	10	29.771	54.204	39.295	8.193
Mg^{2+}	Ashes	4	0.000	318.261	136.230	161.689
	Burnt 2011	10	26.276	889.082	195.140	261.426
	Burnt 2009	10	6.517	29.621	16.383	6.508
	Burnt 2008	10	0.000	35.691	7.387	11.219
	Control	10	6.128	43.153	11.706	11.167
Cl^-	Ashes	4	90.768	373.810	194.060	125.977
	Burnt 2011	10	0.000	84.274	49.175	29.258
	Burnt 2009	10	25.898	41.349	34.460	5.459
	Burnt 2008	10	38.789	71.427	50.096	9.550
	Control	10	21.045	52.415	34.057	10.077
NH_4^+	Ashes	4	0.000	4.634	1.792	2.240
	Burnt 2011	10	0.000	136.674	16.555	42.260
	Burnt 2009	10	2.196	28.798	10.137	7.916
	Burnt 2008	10	1.906	31.795	14.973	10.524
	Control	10	0.000	1.860	0.186	0.588
NO_2^-	Ashes	4	5.806	17.932	9.621	5.644
	Burnt 2011	10	0.000	21.269	4.533	6.218
	Burnt 2009	10	0.189	0.640	0.407	0.139
	Burnt 2008	10	1.010	2.324	1.376	0.419
	Control	10	0.104	0.433	0.183	0.117
NO_3	Ashes	4	2.965	12.431	6.969	4.477
	Burnt 2011	10	0.000	6.567	2.763	1.943
	Burnt 2009	10	0.651	86.293	28.353	26.850
	Burnt 2008	10	4.270	6.991	5.192	0.779
	Control	10	0.578	45.068	5.676	13.850
N tot	Ashes	4	2.623	8.265	5.896	2.773
	Burnt 2011	10	0.000	108.509	14.880	32.970

	Burnt 2009	10	4.444	23.473	14.410	6.873
	Burnt 2008	10	3.596	26.037	13.237	8.106
	Control	10	0.439	10.308	1.482	3.129
PO_4^-	Ashes	4	24.728	630.880	326.693	325.328
	Burnt 2011	10	0.000	1,744.858	181.327	549.435
	Burnt 2009	10	0.000	1.920	0.478	0.763
	Burnt 2008	10	0.000	12.253	2.805	4.858
	Control	10	0.000	4.802	0.946	1.472
SO_4^{2-}	Ashes	4	542.192	5,491.990	2,057.644	2,341.875
	Burnt 2011	10	0.000	1,848.338	549.147	659.471
	Burnt 2009	10	25.249	53.927	36.310	9.939
	Burnt 2008	10	32.349	67.499	42.706	9.548
	Control	10	27.519	81.933	37.233	16.483

V.

Factores de mantenimiento de la regeneración de *Pinus sylvestris* L. en un bosque Mediterraneo potencial de *Quercus pyrenaica* Willd.

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Factors maintaining regeneration of *Pinus sylvestris* L. in a potential Mediterranean *Quercus pyrenaica* Willd. forest

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Introduction

One of the most striking landscape changes in the Spanish Central System – and specifically in the Sierra de Guadarrama– occurs where the forests of *Quercus pyrenaica* Willd. (hereafter melojo oak) give way to forests of *Pinus sylvestris* L. (hereafter Scots pine) along an increasing altitudinal gradient (Rivas-Martínez et al. 1990). Scots pine is a boreal species occurring in the Sierra de Guadarrama at one of the southernmost limits of its distribution; whereas melojo oak is a sub-Atlantic species at the southernmost limits of European broad-leaved forests (do Amaral Franco 1986; 1990). The altitudinal boundary between the Scots-pine and the melojo- oak belts has been the subject of debate (Martínez García 1999), but in any case it allows a mixed vegetation band where Scots pine-based forestry has been favoured (Del Río and Sterba 2009).

The seedling stage is the weakest and most vulnerable part of plant development (Harper 1977). Temperature, invertebrate herbivores, pathogens and interference with existing vegetation have been signalled as the main factors constraining the establishment of Scots pine seedlings in boreal populations (Domisch et al. 2002; Nystrand and Granström 2000; Burdon et al. 1994). By

contrast, summer drought has been shown to be the main agent of seedling mortality in southern-latitude Scots pine populations (Martínez-Vilalta and Piñol 2002; Castro et al. 2004). Scots pine is highly sensitive to severe drought when compared to Mediterranean pine species (De las Heras et al. 2012), from which it can be inferred that Scots pine regeneration could also be sensitive to climatically dry years.

In the last millennium, traditional practices in the Spanish Central System (Pardo and Gil 2005) have included livestock and forestry, using fires to shape the plant landscape (Trabaud 1994; Pausas 1999). Prescribed fires have been applied to obtain pastures by burning woody vegetation (Badia et al. 2002) and also in forestry to counteract pest insects (Pérez and Moreno 1998). A traditional practice defined as "slash-pile prescribed burns" consists of a systematic cleaning of the understory and elimination of unhealthy branches from the canopy, accumulating the remnants of these cuts in piles that are finally burnt under controlled conditions. Some cryptogam species –such as *Funaria hygrometrica* (moss), *Coltricia perennis* and *Psathyrella pennata* (fungi)– have been reported as indicators of recent prescribed slash-pile burns in a mixed *Quercus pyrenaica-Pinus sylvestris* managed forest (Castoldi and Molina 2012).

Experimental studies showed that pine germination is unaffected by temperature up to 70°C but it is depressed from 120°C onwards (Castoldi and Molina in press; Nuñez and Calvo 2000; Habrouck et al. 1999; Álvarez et al. 2007). Scots pine is an obligate seeder (Keeley and Zedler 1978; Nuñez et al. 2003) whose sensitivity to high temperatures has led it to be designated as a rarely pyrophitic species, based on its boreal distribution where the probability of natural fire is very low (Reyes and Casal 1995). However, Scots pine germination is indirectly stimulated by fire through the creation of an appropriate seedbed induced by changes in the soil characteristics and the elimination of herbaceous plant- competitors (Hille and den Ouden 2004). Slash-pile prescribed burns increase pine seedling density (Castoldi and Molina 2013) but it is still unknown whether it also affects their evolution over time.

Our working hypothesis is that prescribed fire management influences Scots pine regeneration in a mixed *Quercus pyrenaica-Pinus sylvestris* managed forest. This work aims to find the human-induced (prescribed fires) and natural (climate) drivers applied to the management and regeneration of Scots pine in a potential melojo- oak forest.

Material and Methods

Study area

The study area is located in the municipality of Rascafría (Madrid) in the eastern part of the Spanish Central System (Guadarrama Mountains, 1200 m a.s.l., 40°54'N, 3°52'O). Data were collected in 2010, 2011 and 2012 in the Biological Field Station of the Complutense University, a woody patch with an extension of about 50 ha located in the bottom of the Paular valley on an almost completely flat terrain (<10 m of altitude excursion). The climate in the study area is sub-Mediterranean, with a mean annual precipitation of 895 mm and a mean annual temperature of 10.1ºC (Elias Castillo and Ruiz Beltrán 1977). Soil substrates in the area correspond to brown soils on silicate rocks (Guerra et al. 1966). The plant landscape consists mainly of a semi-natural forest with patches of young melojo-oak mixed with stands of Scots pine (Castoldi and Molina 2012).

The area underwent about 1,700 slash-pile burns between 1999 and 2009 (A. Canencia pers.com.), each leaving a burnt patch of terrain of about 1 m^2. Depending on the quantity and the type of the materials burnt on each plot, the intensity of the heat to which the underlying terrain was exposed can vary considerably, and potentially affects the regeneration of the vegetation in the plot. We account for this variable by classifying the fire intensity in each plot into three categories (high, medium or low) as deduced by observations of charcoal remains and supported by plot-specific information from the custodian that operated the controlled burn. Traditionally, slash-pile burns are performed each year just before the start of the

drought season (before June). The year each plot was burnt was also recorded (A. Canencia pers.com.).

Seedling regeneration rate

Post-fire regeneration of Scots pine seedlings was studied in ten one-square metre permanent- plots marked with pickets in order to be repeated exactly throughout the whole study period. Five of these plots corresponded to slash-pile prescribed burns performed in 2008 (3 plots) and 2009 (2 plots, Table 1). In 2010 no burns were made in the area due to forest management.

Seedling survival data were referred to 5 plots (and relative controls) in which we individually marked each seedling (N=721). Emergence data were referred to a further 15 plots (and relative controls) in which we only counted the number of seedlings emerged. For each burnt plot we established a control plot by selecting a 1 m^2 area near the burnt plot but located on natural vegetation. Each year, new emerged seedlings were individually marked with a clip with a numbered tag. Individual histories of a total of 721 seedlings were tracked by measuring the height of each seedling with a rule (1 mm precision) on nine different occasions between April 2011 and September 2012 (see exact measuring dates in Figure 4). The height of stem ramification was measured in seedlings when it occurred. In these cases, basal diameter of the stem was also measured by means of a calliper with a 0.1 mm precision.

Table 1 Seedling survival and mortality in burnt and control plots for each year of emergence. Plots 1, 2 and 3 were burnt in 2008 and plots 4 and 5 were burnt in 2009.

Plot N		N° seedling	Year	Survived
1	burnt	2	< 2010	2
		63	2010	45
		3	2011	2
		4	2012	2
	control	6	< 2010	4
		16	2010	8
		2	2011	1
		2	2012	1
2	burnt	0	< 2010	-
		83	2010	37
		3	2011	0
		8	2012	2
	control	3	< 2010	2
		3	2010	1
		2	2011	0
		1	2012	0
3	burnt	0	< 2010	-
		123	2010	102
		6	2011	5
		10	2012	3
	control	6	< 2010	5
		53	2010	47
		2	2011	0
		0	2012	-
4	burnt	0	< 2010	-
		50	2010	15
		9	2011	1
		36	2012	0
	control	0	< 2010	-
		0	2010	-

		0	2011	-
		4	2012	0
5	burnt	0	< 2010	-
		81	2010	53
		6	2011	1
		19	2012	7
	control	2	< 2010	2
		22	2010	10
		1	2011	0
		16	2012	2

Cotyledons were counted in the seedlings emerged in more recent years (2011 and 2012) in order to relate them with seedling survival. In the case that seedlings were found dead, the causes of mortality were recorded, distinguishing between summer drought and herbivory. Seedlings that became brown and dried out during the summer without any visible damage were classified as dead due to summer drought. Seedlings eaten by herbivores appeared with obvious browsing damage, having only the basal stem with the tag remaining. We also related mean monthly rainfall in 2011 and 2012 to seedling survival. In control plots seedlings emerged before 2010 were taken into account in order to record more exhaustive data on the growth rate. We therefore gathered information on 3-year-old seedlings in burn plots and 5-year-old seedlings in control plots.

We also explored the effect on seedlings regeneration rate of eight environmental variables characterising the immediacies of the plots: DBH of the closest pine tree to the plot, DBH of the second closest pine tree to the plot, distance from the closest pine tree to the plot, distance from the second closest pine tree to the plot, number of pine trees in a surrounding radius of 15 metres, oak litter cover, plant cover excluding pine seedlings and canopy openness. Variables were collected in 40 plots distributed throughout the study area (20 burnt and 20 control). The number of pine trees in a 15 metre radius was recorded taking into account that the 75% of seeds fall in this radius from the mother plant (Booth 1984). Canopy

openness was calculated by means of two hemispherical photos taken at the burnt plot: we used a 10 mm fish-eye lens (180º viewing angle, orthographic projection) mounted on a Canon 350 D camera. Pictures were taken in the centre of the plot, at 1.70 meters above the ground, levelled looking upward the sky so as to avoid the overexposed region around the sun. The images were analysed calculating canopy openness with Gap Light Analyser Software (Frazer et al. 1999).

Statistical analyses

As a first step we compared the difference between the number of emerged seedlings on burnt and control plots by paired t-tests. Given that the aim of this test was not to check for differences among seedlings emerged in different years, the number of seedlings emerged during the whole period were pooled together. We performed this test both with the data from the 5 burnt plots (and relative controls) and for a further 15 burnt plots (and relative controls). A paired t-test was also used to compare the percentage of seedlings that survived after the first growth year between burnt and control plots. We compared seedling height measured on nine different occasions between April 2011 and May 2012 by means of ANOVAs, and then measured the growth rate with linear regressions.

The influence of environmental variables on seedling survival was explored through a binomial logistic regression –with a binary value (0: survived, 1: dead) as the dependent variable–, of individual seedlings and the eight environmental variables as continuous predictors (see Table 1). Non-significant variables ($p>0.05$) were progressively removed from the model. Analyses were carried out in STATISTICA and SPSS 13.0 software.

Results

The comparison of seedling survival between winter and summer over two consecutive years (2011 and 2012) indicated that live seedlings always outnumbered dead seedlings, and that seedling mortality was related to drought (Figure 1; Figure 2). Although mean annual precipitation was not significantly different between 2011 and 2012, the more balanced rainfall distribution throughout spring in 2011 may help explain the higher seedling mortality in 2012. Furthermore, summer was the least unfavourable season for seedling recruitment.

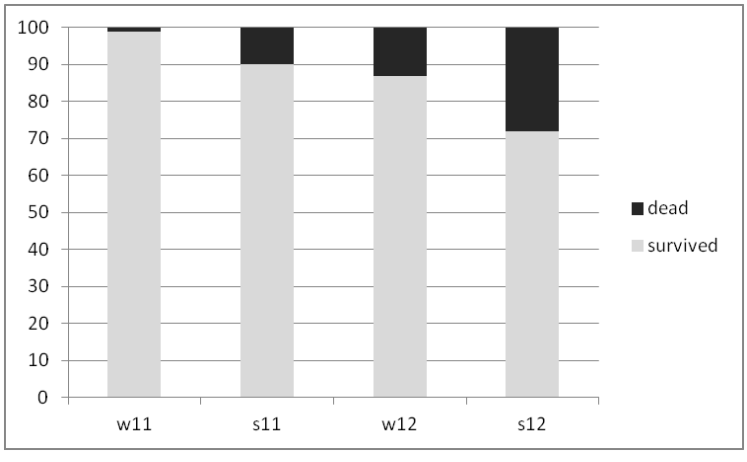

Fig. 1 Percentage of seedlings found dead (brown bars) and survived (green) in winter and summer of 2011 and 2012. w11: winter 2011, s11: summer 2011, w12: winter 2012, s12: summer 2012

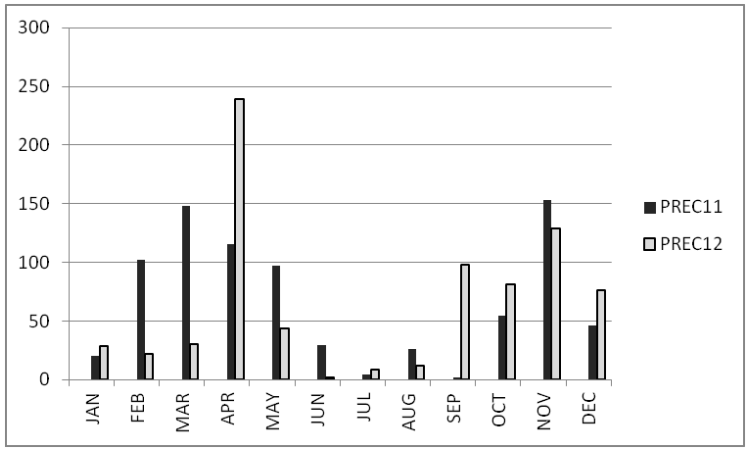

Fig. 2 Mean monthly rainfall in 2011 and 2012. Data provided by the metereological station located in the Biological Field Station of the Complutense University

Indeed, if we remove the only case in which survival was higher in control than in burnt plots, the test resulted in strong significance (t=5.228, p=0.014), showing a clear tendency towards a higher survival rate of seedlings in burnt plots.

The number of emerged seedlings differed dramatically in burnt and control plots (t=9.104, p=0.001), and was much higher in the burnt plots (burnt: mean±s.d.=101.20±24.47; control: 28.20±23.45 (N=5)) (black bars in Figure 3). This evidence was confirmed by emergence data collected in a further 15 plots in 2010: burnt: mean±SE=149.40±67.50; control: 38.05±33.93 (N=20); t=6.659, p<<0.001. Survival tended to be higher in burnt (53.17±24.81) than in control plots (41.31±31.26), but this difference was slightly below the limit of significance (t=2.324, p=0.081) (grey bars in Figure 3).

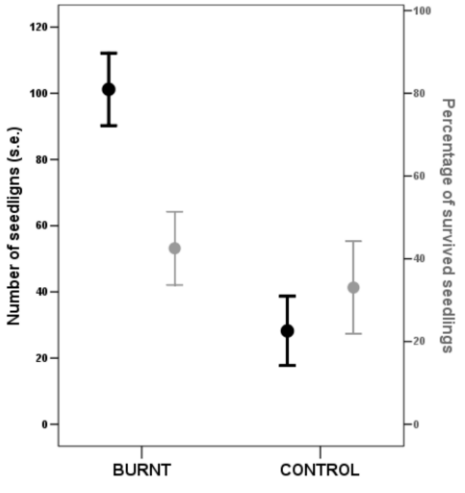

Fig. 3 Comparison between burnt and control plots in mean number of emerged seedlings (black bars) and mean percentage of seedlings surviving to the first year (grey bars). Whiskers represent standard errors

Differences in seedling growth between burnt and control plots are shown in Figure 4. The growth spurt took place between May and June. At emergence (first measure for each year performed in April-May) seedlings were higher in control than in burnt plots (for seedlings emerged until 2011: $F_{1,600}$=9.986, p=0.002; for seedlings emerged in 2012: $F_{1,101}$=11.724, p=0.001).

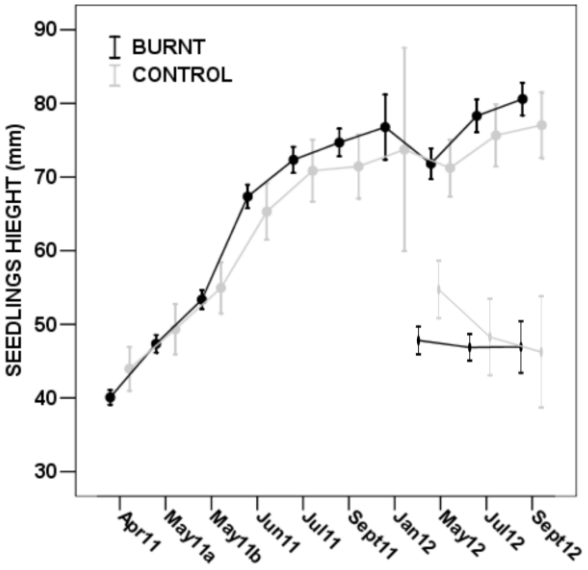

Fig. 4 Comparison of seedling height between burnt (black) and control (grey) plots as measured on nine progressive occasions between April 2011 and September 2012. Whiskers show 2 x standard error. The right corners separately show seedlings emerged in 2012

This trend was lost over a long timescale, given that seedling growth in burnt and control plots tended to reach equal height in the following months (no significant differences in all other cases, details not shown). However, the growth rate in burnt plots [β(SE)=1.735 (0.05)] was higher than in control plots [β(SE)=1.453(0.109)].

The cotyledon number did not affect seedling height in the preliminary development stages (all correlations with the first three measures in spring had a $p>0.05$). However, cotyledon number was slightly positively correlated with survival time ($r=0.165$, $p=0.053$).

Logistic regression exploring the influences in environmental variables on seedling survival indicated that the DBH of the second nearest pine tree (but not of the nearest one) and the oak litter cover positively influenced seedling survival [DBH2: β(SE)=0.174(0.019), $p<0.001$; BOak: β(SE)=0.015(0.004), $p<0.001$] (see Figure 5). All the other environmental variables were excluded from the model ($p>0.05$), meaning that they had no primary influence on Scots pine seedling survival. In burnt plots a positive relationship was found between seedling emergence and the surrounding pine tree density ($r=0.45$, $p=0.042$).

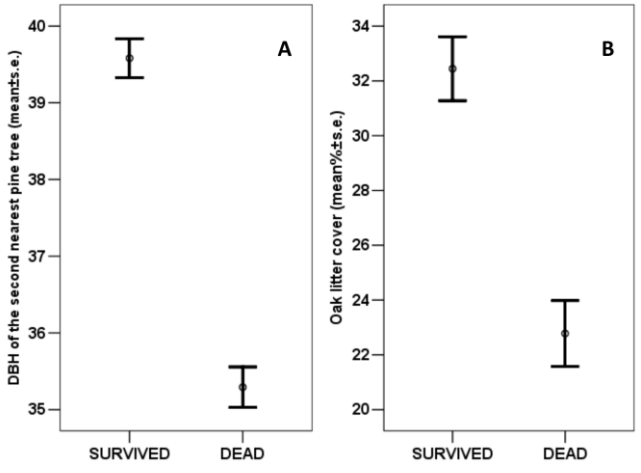

Fig. 5 Mean values of DBH of the second nearest pine tree (A) and mean percentage of oak litter cover (B) for seedlings that died or survived during their first year of growth. Whiskers show standard errors

Discussion

Our results showed that under a sub-Mediterranean climate in a mixed forested area of Scots pine, the seedling survival rate prevailed over mortality. Seedling survival was related to the climatic year and summer drought, which is the main filter for survival (Castro et al. 2004). This may help explain some ecological patterns. In Spanish mountains ranges such as the Sierra de Guadarrama, Scots pine woodlands are found at higher altitudes and are replaced downwards by melojo oak forest along an increasing Mediterraneanity gradient. In a climate change scenario with expectations of longer dry seasons (Parmesan 2006), the best option for Scots pine regeneration is to be confined to higher altitudes, as confirmed in the Spanish mountains areas by observations of progressive substitution by more drought-tolerant oak (Galiano et al. 2010).

Fire removes the organic soil layer and herbaceous vegetation, allowing pine seedling recruitment (Hille and Ouden 2004). Our results showed not only a higher Scots pine seedling emergence rate but also higher survival after slash-pile burns. This type of management can be considered a tool for the regeneration of pine stands, in view of the fact that in a forested environment such as the study area, the understory mitigates this regeneration. This management also provides taller

seedlings over time due to a soil nutrient enrichment through the increase in pH, usable P and exchangeable Mg (Christensen 1977, Vega et al. 2009).

Scots pine on dry sites show architecural adaptations −thick bark, greater distance between the ground and the canopy− to low intensity fires (Agelstam and Kuuluvainen 2004). In the case of southern Scots pine populations, characterised by a higher seed mass in comparison with northern populations (Reich et al. 1994), seed mass mitigates the negative effects of temperature on seed germination (Castoldi and Molina in press). Our results also showed that cotyledon number positively affected seedling survival, but not seedling height. Since, cotyledon number is positively correlated to seed mass (Castoldi and Molina in press), it could be inferred that cotyledon number is an indicator of maternal plant fitness.

Scots pine has wind seeds, with a dispersing capacity that covers distances from 50 up to 100 m from the parent (Skilling 1990). Our results indicated that for more effective seedling survival there must be a certain distance from the tree parent (seedling survival was correlated to the DBH of the second nearest pine tree). It is known that accumulation of litter favours seedling emergence in large-seeded tree species in mixed oak-Scots pine forests (Dzwonko and Gawroński 2002). Our results proved that melojo- oak litter confers a nursery effect on seedling pine survival and that pine tree density positively affects seedling survival. In terms of prescribed slash-pile management, the burn is more effective in promoting Scots pine seedlings when it occurs in areas with a high density of pine trees and in a melojo- oak forested environment. These apparently contradictory facts concur with the forestry practices whereby the advisability of favouring *P. sylvestris-Q. pyrenaica* mixed stands with a higher proportions of pine trees is greater than the benefits of a more complex forest, while retaining an acceptable level of wood production (Del Río and Sterba 2009). The knowledge of the regeneration processes of Scots pine stands is a key concept for sustainable management.

Conclusions

Management by means of prescribed burns increases recruitment of Scots pine seedlings and favours their growth and survival. This pattern is more evident when burn management is carried out in a mixed Scots pine-melojo oak forest where the tree canopy layer and oak litter act as a seedling nursery. In Mediterranean areas Scots pine has adapted its genetic and morphological features to withstand low-intensity fires. In a climate change scenario, the post-fire regeneration of Scots pine woodlands is optimised at higher altitudes where the effect of drought is more attenuated.

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Apéndice 3

El papel de lluvia de semillas en la regeneración post-fuego en un bosque mixto de pino y melojo

Apéndice 3

Role of seed rain in after-fire regeneration in a mixed pine-oak forest

El papel de lluvia de semillas en la regeneración post-fuego en un bosque mixto de pino y melojo

Introduction

The high cost of plantations, the demand for natural landscapes and the multi-resource use of forests focus European foresters' attention on natural regeneration (Ackzell 1993). There are several ways in which forest communities can regenerate. Seedlings can be recruited from seeds recently dispersed to the site (seed rain) or from seeds stored in the soil (seed bank) (Álvarez-Buylla and Martínez-Ramos 1990). When burn acts it can deeply modified seed bank, thus seed rain can be very important in shaping early succession community structure. A traditional practice defined as "slash-pile burning" consists of a systematic cleaning of the understory and elimination of unhealthy branches from the canopy, accumulating the remnants of these cuts in piles that are finally burned using spot burning method. In our work we aimed to investigate the effect of seed rain in shaping the early post-fire plant succession composition in slash-pile prescribed burns of a sub-Mediterranean managed forest.

Material and methods

Twenty burnt plots (ten burnt in spring 2008 and ten burnt in spring 2009) and 20 control plots closed to the burnt plots were established in the study area (Castoldi et

al. 2012). We placed 12 seed traps (6 corresponding to plots burnt in 2008 and 6 corresponding to plots burnt in 2009) made of green, plastic turf mats (squares each of 15 cm side) after removal of vegetation (Molau 1996) between burnt and control plots. We placed an adhesive belt around the seed traps in order to avoid seed predation. Seed traps were collected to remove all the seeds fallen on them and were replaced with empty new ones in order to have seeds rain data in September 2010, March 2011 and September 2011 (immediately after the summer and after the winter). *Pinus sylvestris* male strobili fallen into seed traps were also counted. Seeds were identified to taxonomic units (genera and species) with stereomicroscope, with reference to Digital Seed Atlas (Cappers et al. 2006, Castoldi et al. unpublished data). We related the species richness value found in burnt plots (Castoldi et al. 2012) to our seed rain results in order to investigate if the colonization is driven by soil seed bank resistant to fire or by seed rain after the burns. One-way ANOVA was performed to determine significant differences between seeds collected in summer and winter (STATISTICA software). Spearman's rank correlation coefficient was used to relate male strobilus with the number of cones, in order to have an indicator of pine trees fitness.

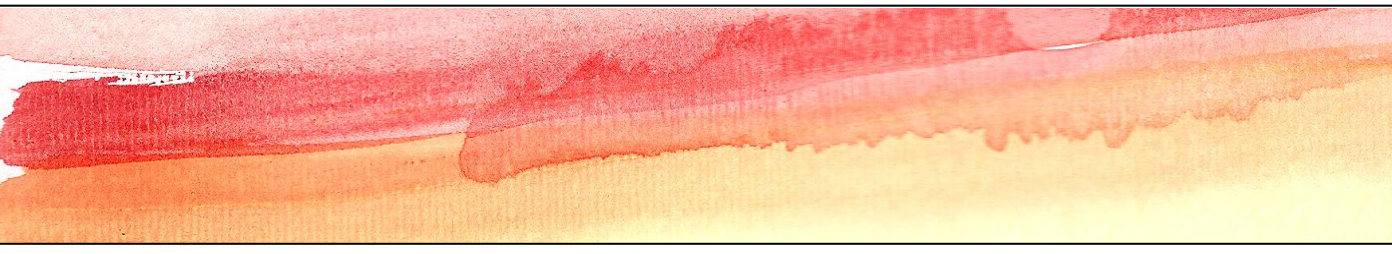
Results

Descriptive statistics of seeds rain results are reported in Table 2. There was no significant difference between number of seeds collected in September 2010 and September 2011 (mean 2010=23.5, SD=57.53; mean 2011=25.5, SD=48.97; $F_{1,22}=0.008$, $p=0.928$) and neither between number of seeds collected in March 2011 and September 2011 (mean March=2.41, SD =1.05; mean September=25.5, SD =48.97; $F_{1,22}=2.663$, $p=0.117$). There was difference between seasons in the plant composition. In March we found *Pinus sylvestris, Ornithopus perpusillus, Poa, Trifolium* whereas in September we found taxa such as *Apiaceae, Arenaria montana, Clinopodium vulgaris, Geranium, Myosotis, Ornithopus perpusillus, Poa, Prunella,*

Rumex, *Trifolium*, *Vicia*. There was significant difference between mature male strobilus collected in September 2010 and September 2011 (mean 2010=131.50, SD =103.34; mean 2011=385.00, SD=203.08; $F_{1,22}=14.85$, $p=0.001$) and between mature male strobilus collected in March 2011 and September 2011 (mean March=56.33, SD=33.05; mean September=385.00, SD=203.08; $F_{1,22}=30.61$, $p<0.001$). Male strobilus fallen in spring-summer 2011 (s11) are positively related with the number of cones found in the plots ($r=0.74$, $p<0.01$). We found significant difference between species richness in burnt plots and seed rain diversity results (mean burnt plots=18.44, SD=30.22; mean seed rain=6.06, SD=7.52; $F_{1,56}=4.580$, $p=0.03$).

Table 2. Seed rain results. Season correspond to the moment of the year when seed traps were collected. s10: September 2010, s11: September 2011 and m10: March 2010

	Season	**N**	**Mean**	**SD**	**Min**	**Median**	**Max**
Nb of seeds	s10	12	23.50	57.53	0.00	2.50	199.00
	s11	12	25.50	48.97	0.00	4.50	154.00
	m10	12	2.41	1.50	1.00	2.00	6.00
Seed mass	s10	12	0.03	0.06	0.00	0.005	0.20
	s11	12	0.02	0.04	0.00	0.009	0.14
	m10	12	0.01	0.009	0.001	0.009	0.03
Seed diversity	s10	12	2.41	2.74	0.00	1.50	9.00
	s11	12	3.25	3.01	0.00	2.50	11.00
	m10	12	1.41	1.31	0.00	1.00	4.00
Male pine strobila	s10	12	131.50	103.34	10.00	79.50	318.00
	s11	12	385.00	203.08	70.00	375.00	800.00
	m10	12	56.33	33.05	15.00	45.50	107.00



Discusión General

De los 12 hábitats identificados en la Estación Biológica UCM, dos corresponden a ambientes relacionados con la sucesión primaria. Estos son: a) suelos recientemente quemados colonizados por criptógamas donde *Funaria hygrometrica* juega un papel importante (Delasheras et al. 1994); y b) suelos aluviales de cauces colonizados por vegetación herbácea helofítica caracterizada por *Oenanthe crocata* (Molina y Moreno 1999). Los ambientes higrófilos aportan una gran biodiversidad en el área. De ellos, los hábitats fontinales, caracterizados en la Estación por herbazales de *Myosotis stolonifera* y de *Veronica anagallis-aquatica* son conocidos por su resiliencia a las variaciones climáticas (Jeffres et al. 2009). Son por tanto ecosistemas adecuados para el estudio del cambio global. Los prados en el área de estudio están distribuidos según un gradiente hídrico: los pastos de *Agrostis castellana* que se encuentras en suelos húmedos con condiciones de prolongada sequía estival, mientras que los pastos de *Cynosurus cristatus* están sometidos a una sequía estival más breve (Fernández-González 1988, Rodríguez-Rojo y Sánchez-Mata 2004). Finalmente los ambientes forestales y sus orlas constituyen la mayor parte dl paisaje vegetal de la Estación.

La Estación Biológica alberga dos tipos de hábitat de interés comunitario listados en la Directiva 92/43/CEE que corresponden a: a) cursos de agua de llanura o montanos con vegetación de *Ranunculion fluitantis* y *Callitricho-Batrachion* (hábitat 3260) y b) los robledales de *Quercus pyrenaica* del NO Ibérico (hábitat código 9230) −92/43/CEE, García & Jiménez 2009−. Las amenazas a que se enfrentan estos hábitats en el territorio están relacionadas con el cambio climático. Los ecosistemas acuáticos de aguas dulces son uno de los más amenazados por el cambio global (Wilby et al. 2010). Por otra parte, los melojares que presentan una disminución en su areal en las últimas décadas (Barbour et al. 2007), son sensibles a la sequía causada por el cambio climático (Hernández-Santana et al. 2009).

La identificación de 280 plantas vasculares en la Estación Biológica UCM supone que la Estación Biológica que ocupa un 0.1% del valle del Paular encierra un 21%

de su riqueza florística. Esto se explica por la alta riqueza vegetal que presentan los bosques subhúmedos de *Quercus pyrenaica* en comparación con otros ecosistemas (Fernández-González 1988, Fernández-González 1991).

Se ha señalado que la germinación del pino silvestre se anula entre los 120ºC y 150ºC (Habrouk et al. 1999, Escudero et al. 1997, Nuñez y Calvo 2000) así como que tratamientos de calor retrasan significativamente el tiempo de germinación (Escudero et al. 1997, Habrouk et al. 1999). Nuestros resultados muestran que la temperatura y el tiempo de exposición afectan el tiempo de germinación incluso después de haber sometido las semillas a temperatura moderadas (inferiores a 100ºC). Diferentes estudios sobre la influencia de la masa de la semilla en la germinación de diferentes especies de pino muestran resultados contradictorios. Algunos citan una correlación positiva (Simak y Gustafsson, 1954; Debain et al, 2003; Tíscas y Lucas, 2010), mientras que otros estudios no muestran ningún efecto (Mikola, 1985; Zaborovskii, 1966; Parker et al, 2006; Bladé y Vallejo, 2008). En poblaciones españolas de pinos silvestres, la masa de semillas se ha correlacionado positivamente con la germinación (Castro, 1999). Esto se halla de acuerdo con nuestros resultados sobre *Pinus sylvestris* var. *iberica* donde la masa de las semillas se relaciona positivamente con la germinación cuando las semillas no son tratadas con calor. Por otra parte, la masa de las semillas todavía influye positivamente en la capacidad de germinación cuando son moderadamente calentadas y aún conservan la capacidad de germinar. La masa de la semilla se ha relacionado positivamente con el número de cotiledones (Reich et al., 1994), como nuestros resultados también apoyan. Se puede inferir, por tanto, que las semillas con un mayor número de cotiledones tras ser sometidas a calor moderado podrían tener un mejor rendimiento en la germinación.

Nuestro estudio sobre la sucesión vegetal temprana tras quemados recientes de residuos de corta destaca la importancia de las criptógamas en comparación con las fanerógamas como indicadores de quemados recientes. Los tres taxones revelados aquí como especies características son *Funaria hygrometrica*, *Psathyrella pennata* y

Coltricia perennis, los cuales son también conocidos como colonizadores de suelos post-incendio bajo diferentes climas extratropicales (Visser 1995; Baar 1996). En situaciones post-incendio, los musgos pueden actuar como los primocolonizadores, formando tempranamente una capa densa que favorece a nivel local el establecimiento de nuevas especies (Bradbury 2006). En concreto, el musgo *Funaria hygrometrica* está relacionado con lugares temporalmente inestables, en particular las superficies calcinadas (Delasheras et al. 1994, Esposito et al. 2009), y prepara el terreno para una colonización posterior de las plantas vasculares, así como contrarresta la erosión de las primeras etapas post-incendio. Sin embargo la flora vascular encontrada en las etapas tempranas tras el incendio se parece mucho a la composición florística inicial (Purdie y Slatyer 1976), que en el caso de nuestro estudio consiste principalmente en plantas de la vegetación de los alrededores, tales como vegetación del sotobosque y de las orlas forestales. Los terófitos pueden ser un componente importante en las primeras etapas de la sucesión post-incendio, jugando un papel importante en la prevención de la pérdida de nutrientes del suelo (Castoldi et al. 2012, Kazanis y Arianoutsou 1996, Pérez y Moreno 1998, Guo 2001). Sin embargo, el fuego relativamente influye en los patrones de diversidad de formas de crecimiento (Lloret y Vilà 2003). Nuestros resultados muestran que, aunque los terófitos son favorecidos tras las quemas de residuo de corta, los hemicriptófitos siguen siendo dominantes; estos son también las formas de crecimiento dominantes en el paisaje vegetal circundante.

Los picos de diversidad de especies en las etapas tempranas post-incendio parece estar favorecida por factores diferentes a los picos de diversidad posteriores (Keeley et al. 2005). En la sucesión vegetal temprana de quemados de residuos de corta encontramos dos niveles dentro de la sucesión vegetal en los dos primeros años posteriores al incendio que se caracterizan por un aumento de la riqueza de especies, y, específicamente, en un aumento en la cobertura de dos especies características, *Funaria hygrometrica* y *Coltricia perennis*.

Nuestros resultados también mostraron que la supervivencia de las plántulas pino silvestre prevalece sobre la mortalidad. El año climático y la sequía del verano actúan de filtro principal en la supervivencia de las plántulas de pino silvestre (Castro et al. 2004) lo que puede ayudar a explicar algunos patrones ecológicos. En la Sierra de Guadarrama, los bosques de pino silvestre se encuentran en altitudes más altas y son sustituidos en cotas menores por los melojares conforme aumenta el gradiente de mediterraneidad. En un escenario de cambio climático con expectativas de estaciones secas más largas (Parmesan 2006), habrá mejor regeneración del pino silvestre a altitudes más altas, como confirma el hecho que en las zonas montañosas de España se observa una sustitución progresiva del pino silvestre por el melojo más tolerante a la sequía (Galiano et al. 2010).

El fuego elimina la capa orgánica del suelo y la vegetación herbácea, permitiendo el reclutamiento de las plántulas de pino (Hille y Ouden 2004). Nuestros resultados muestran no sólo una mayor tasa de emergencia en plántulas de pino silvestre sino también una mayor supervivencia tras quemados de residuos de corta. Este tipo de manejo puede ser considerado, por tanto, una herramienta en la regeneración de masas de pino, en vista del hecho de que en un ambiente forestal como el del área de estudio, el sotobosque mitiga esta regeneración. Esta gestión también proporciona plántulas más altas con el tiempo debido al enriquecimiento de nutrientes del suelo mediante el aumento del P utilizable y Mg intercambiable (Christensen 1977, Vega et al. 2009).

Las poblaciones meridionales europeas de pino silvestre, se caracterizan por una mayor masa de semilla en comparación con la de las poblaciones septentrionales (Reich et al. 1994). Este incremento ayuda a mitigar los efectos negativos de la temperatura sobre la germinación de semillas (Castoldi y Molina, en prensa). Nuestros resultados también mostraron que el número de cotiledones afecta positivamente la supervivencia de plántulas, pero no su tamaño. Dado que, el número de cotiledones se correlaciona positivamente con la masa de la semilla

(Castoldi y Molina, en prensa), se puede inferir que el número de cotiledones es un indicador del éxito reproductivo de la planta materna.

El pino silvestre tiene semillas aladas, con una capacidad de dispersión que cubre distancias de entre 50 a 100 m desde la matriz (Skilling 1990). Nuestros resultados indican que para la supervivencia más eficaz de las plántulas debe haber una cierta distancia desde el árbol matriz. Se sabe que la acumulación de hojarasca favorece la emergencia de plántulas de especies de árboles con semillas grandes en los bosques mixtos de pino silvestre-melojo (Dzwonko y Gawronski 2002). Nuestros resultados demuestran que la hojarasca del melojo confiere un efecto vivero en la supervivencia de plántulas de pino y que la densidad de árboles de pino afecta positivamente a la supervivencia de las plántulas. En términos de manejo forestal la quema de residuos de corta es más eficaz en la promoción de las plántulas de pino cuando se efectúa zonas con una alta densidad de pinos y en un entorno boscoso de melojo. Estos hechos aparentemente contradictorios están de acuerdo con las prácticas forestales que favorecen una mayor proporción de árboles de pino en bosques mixtos de *Pinus sylvestris* y *Quercus pyrenaica* (Del Río y Sterba 2009). El conocimiento de los procesos de regeneración de rodales de pino silvestre es un concepto clave para la gestión sostenible.

Conclusiones

I. En la Estación Biológica UCM se identificaron 12 comunidades vegetales tipo agrupadas en siete grupos principales repartidas del siguiente modo: a) una comunidad forestal; b) una comunidad arbustiva de orla de bosque; c) una comunidad herbácea de lindero de bosque; d) dos comunidades de prados; e) una comunidad herbácea nitrófila de lindero de bosque; f) una comunidad pionera de suelos alterados g) cinco comunidades higrófilas y acuáticas.

II. Se reconocieron dos tipos de hábitat listados en la Directiva 92/43/CEE. Estos son: a) robledales de *Quercus pyrenaica* del NO Ibérico (hábitat código 9230); y b) cursos de agua de llanura o montanos con vegetación de *Ranunculion fluitantis* y *Callitricho-Batrachion* (hábitat 3260).

III. La Estación Biológica UCM alberga una alta riqueza florística. Con 280 especies vegetales identificadas supone que un área con una extensión del 0.1% del valle del Paular encierra el 21% de su flora.

IV. Se encontraron siete especies de interés regional para su conservación. Estas son: *Ilex aquifolium* L. (SE), *Lilium martagon* L. (SE), *Malus sylvestris* Miller (IE), *Prunus padus* L. (VU), *Ranunculus valdesii* Grau (VU), *Sorbus latifolia* (Lam.) Pers. (SE), *Taxus baccata* L. (SE).

V. El estudio en condiciones experimentales de laboratorio sobre la influencia de la temperatura en la germinación de *Pinus sylvestris* var. *iberica*, mostró que las semillas con mayor masa mitigan los efectos negativos de la temperatura sobre la germinación tras el tratamiento térmico moderado que simula fuego.

VI. El estudio de la sucesión vegetal en campo tras la quema de residuos de corta en un ambiente forestal sub-mediterráneo, identificó las siguientes tres especies primocolonizadoras caracteristicas, todas criptógamas. Estas son: *Funaria hygrometrica* (Bryophyta), *Psathyrella pennata* y *Coltricia perennis* (Basidiomycota).

VII. Se identificaron dos etapas de sucesión vegetal temprana tras quemas de residuos de corta relacionados con la riqueza de especies y la cobertura de *Funaria hygrometrica*.

VIII. La perturbación por quema de residuos de corta produce en el suelo un aumento significativo del pH y de los iones solubles, y una disminución significativa de la materia orgánica. El suelo a lo largo de los tres primeros años después del quemado experimenta una disminución significativa de concentración en iones.

IX. El manejo mediante quema de residuos de corta aumenta el reclutamiento de plántulas de pino silvestre y favorece su crecimiento y supervivencia. Este patrón es más evidente cuando el manejo se efectúa en un bosque mixto de pino silvestre y melojo, donde el dosel arbóreo y la hojarasca de melojo actúan como vivero de plántulas (seedling nursery).

X. La comparación entre la riqueza de especies en lluvia de semillas y la de los primeros estadíos de sucesión reveló un banco de semillas latente en suelos quemados por residuos de corta.

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